

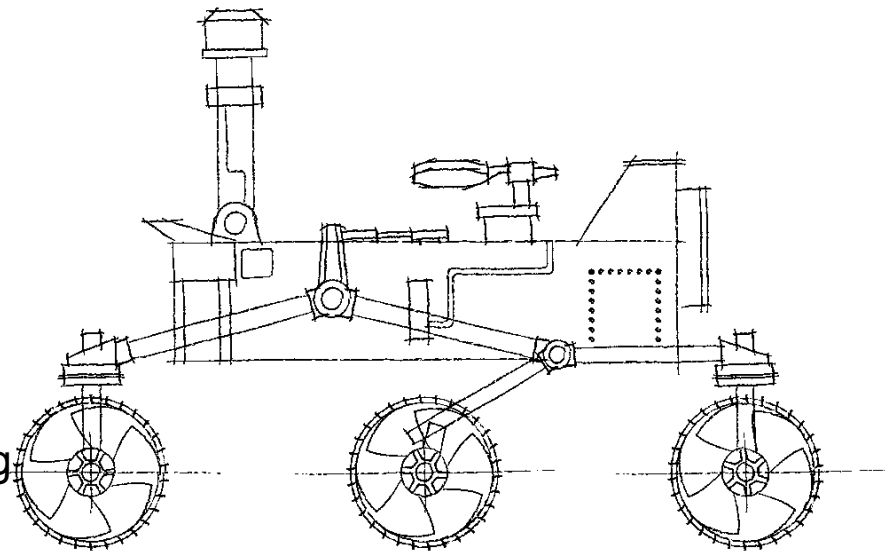
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Mars 2020

Spacecraft and Mission Introduction, Science
Cleanliness and Planetary Protection Work-to-Date

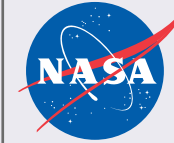
Adam Steltzner (CE)
Ken Farley (PS)
Douglas Bernard (PSE)

Planetary Protection Subcommittee Meeting
NASA HQ
12/9/15



Mars 2020 Project

Overview



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Mars 2020 Project

Purpose:

- Brief the PPS on the Mars 2020 Spacecraft, Mission, Sample Caching, Science Cleanliness and Planetary Protection Approaches and Work-to-Date

Agenda:

- Mission Overview and Science Discussion (Farley)
- Planetary Protection Requirements (Bernard)
- Hardware Overview and Cleanliness Approach (Steltzner)
- Bounding Meta Analysis of PP Performance (Bernard)
- Open Items and System Reviews-to-Date (Bernard/Steltzner)
- Summary (Bernard)

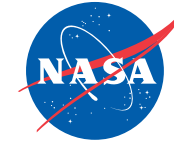
Key Messages



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- Mars 2020's central challenges are fundamental and not the result of a design or architecture choice
 - We are a “subsystem” sterilization approach consistent with 8020.12
 - Requires sealing clean elements from recontamination
 - Requires operational transport analysis for Mars use
- Mars 2020 has been architected to meet the cleanliness challenge of our responsibilities related to potential sample return
 - Under constraints of a heritage hardware re-flight
 - Principals of cleanliness guide our architecting
 - We have formulated and are performing a test and end-to-end analysis effort to show how our design meets the requirements
 - Preliminary results continue to show large ($>10^4$) margins to requirements
- We have performed a bounding “meta-analysis” that does not rely on the same level of detailed understanding of bugs/vehicle
 - Results show good margin (>10) to requirements under a wide range of analysis assumptions



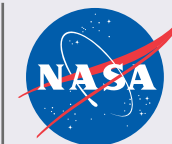
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Mars 2020 Project

Mission/Science / Science Integrity Overview

Farley

Mars Exploration in This Decade

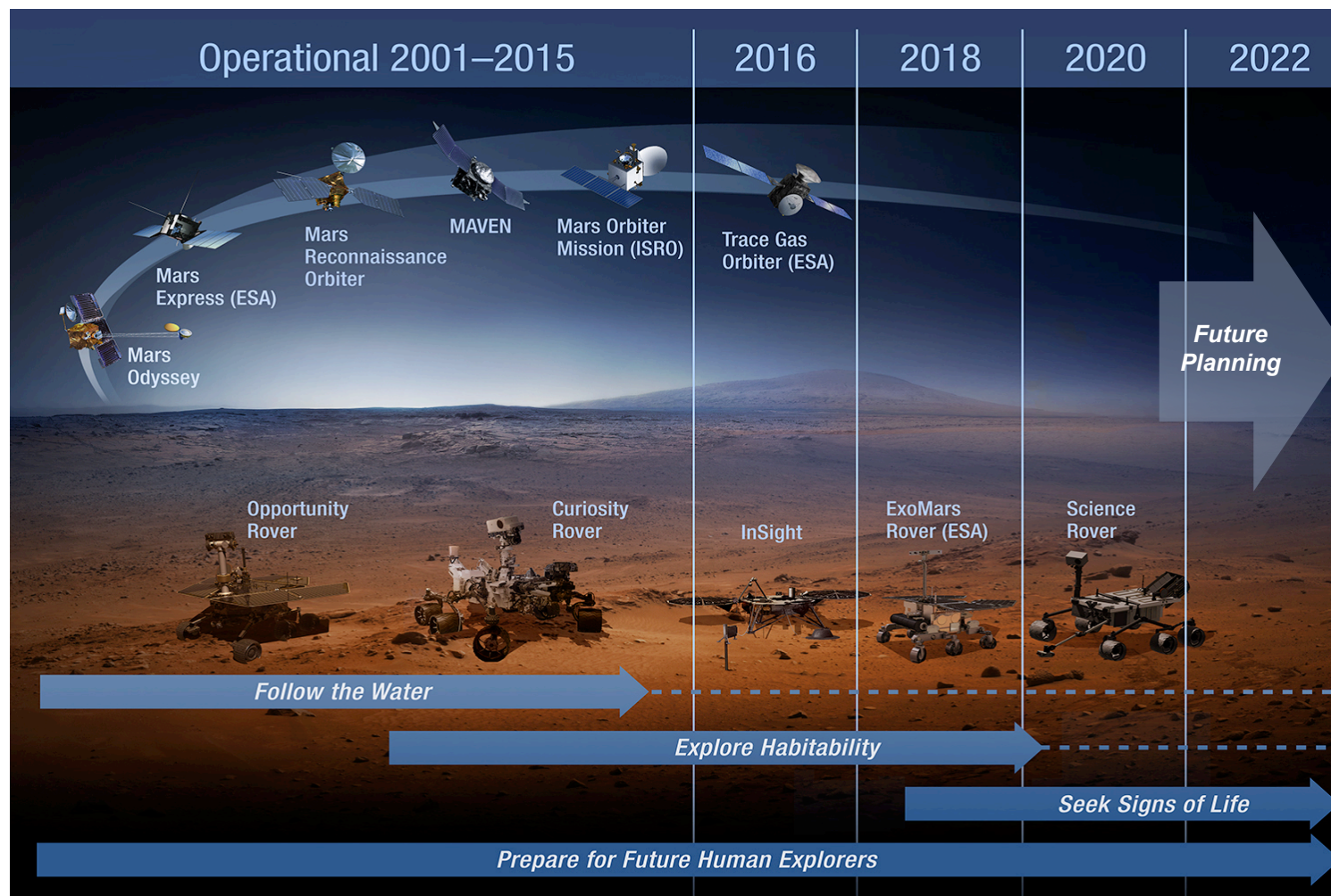


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Baseline Mars 2020 mission addresses the highest priority science

- Builds on Curiosity results by investigating a landing site for possible bio-signature preservation in full geologic context
- Provides HEOMD/STMD contributions to address key Strategic Knowledge Gaps
- Provides cached samples for possible return – *highest priority of Decadal Survey*

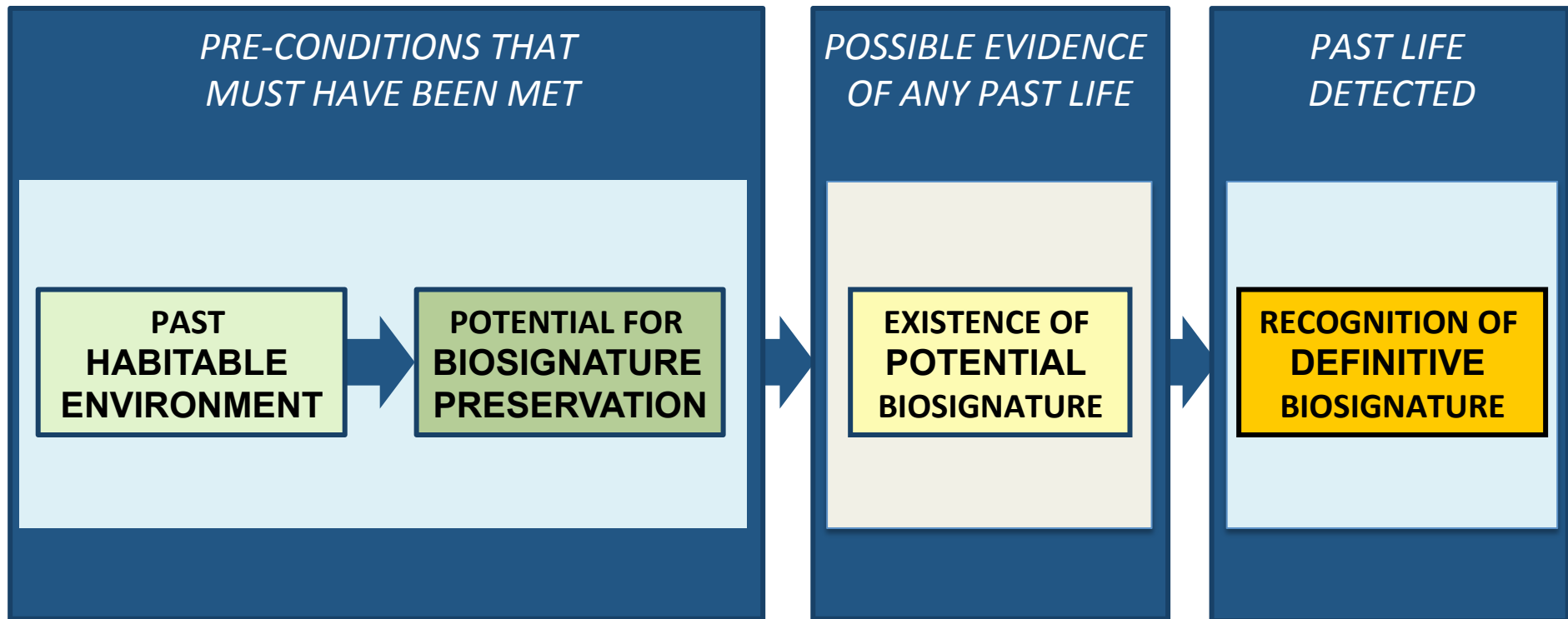


Biosignatures: seeking the signs of ancient life

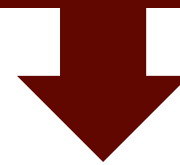


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Proposed Mars 2020 Rover



Mars Sample Return

Labs on Earth

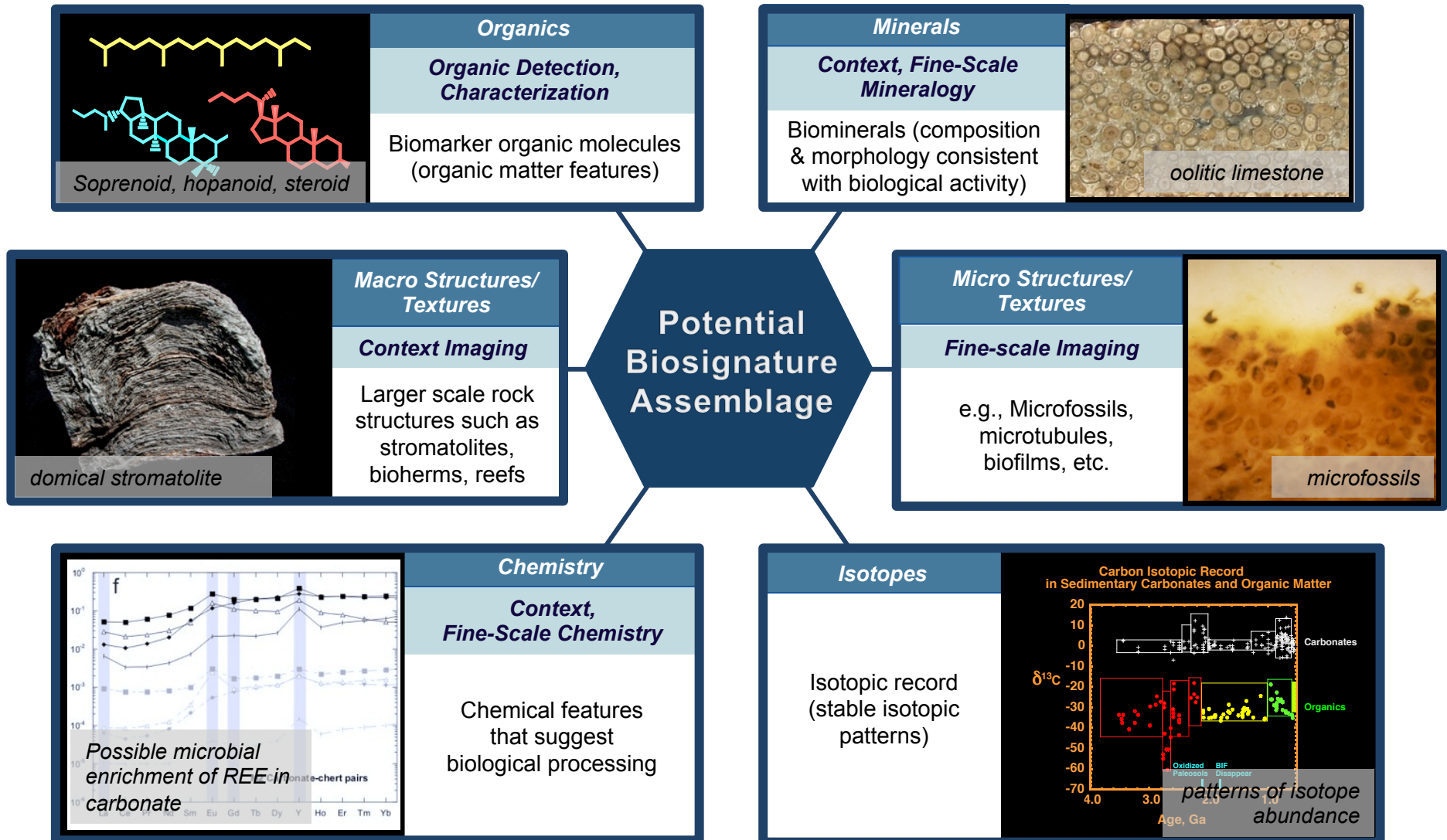
*From the Mars 2020 Science
Definition Team Report
(Mustard et al. 2014)*

Biosignatures: seeking the signs of ancient life



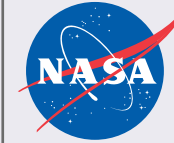
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From the Mars 2020 Science
Definition Team Report
(Mustard et al. 2014)

Mars 2020 Mission Objectives



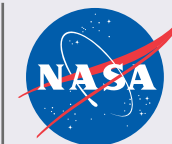
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- **Conduct Rigorous *In Situ* Science**
 - A. **Geologic Context and History** Carry out an integrated set of context, contact, and spatially-coordinated measurements to characterize the geology of the landing site
 - B. **In Situ Astrobiology** Using the geologic context as a foundation, find and characterize **ancient** habitable environments, identify rocks with the highest chance of preserving **signs** of **ancient** Martian life if it were present, and within those environments, seek the signs of life
- **Enable the Future**
 - C. **Sample Return** Assemble rigorously documented and returnable cached samples for possible future return to Earth
 - D. **Human Exploration** Facilitate future human exploration by making significant progress towards filling major strategic knowledge gaps and...
Technology ...demonstrate technology required for future Mars exploration
- **Execute Within Current Financial Realities**
 - Utilize MSL-heritage design and a moderate instrument suite to stay within the resource constraints specified by NASA

These are a thoroughly integrated set of objectives to support Agency's Journey to Mars

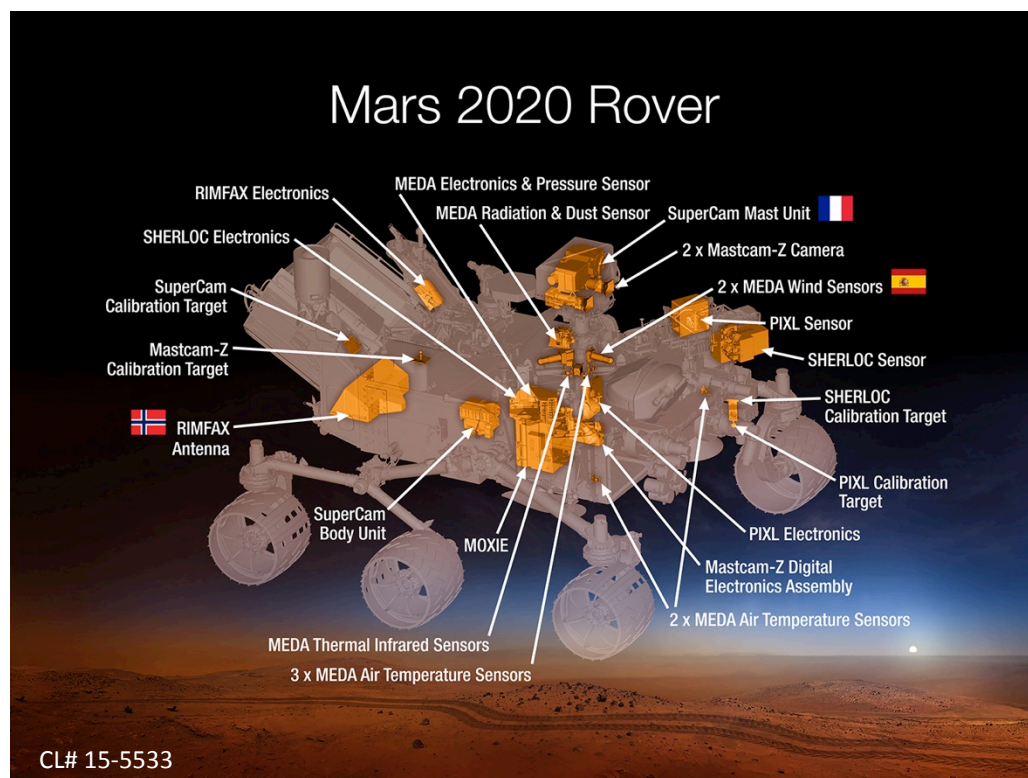
Mars 2020 Payload



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1. **Mastcam-Z** - stereo zoom camera
2. **Supercam** - remote elemental chemistry and mineralogy
3. **SHERLOC** - fine-scale organic geochemistry and mineralogy (mapping)
4. **PIXL** - fine-scale elemental chemistry (mapping)
5. **RIMFAX** - subsurface structure - ground penetrating radar (Norway)
6. **MEDA** - weather and atmospheric dust monitoring (Spain)
7. **MOXIE** - ISRU – conversion of atmospheric CO₂ to O₂



The Mars 2020 Project Science Group is unanimous that these instruments cannot plausibly confirm the existence of martian life nor even a definitive biosignature

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Mars 2020 Science Requirements



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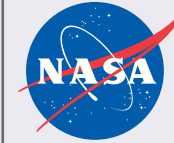
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Science-based requirements related to life detection and biosignatures:

1. Inorganic contaminants – detailed list of elemental contaminant limits developed in consultation with a community working group (Returned Sample Science Board (RSSB) predecessor)
2. Organic contaminants – Total Organic Carbon (TOC) and individual compound limits recommended by Organic Contamination Panel (OCP)
3. Other sample quality factors – limits on things like induced fractures, maximum temperature, magnetic field characterization – RSSB and predecessor
4. Biologic contamination
 - OCP TOC limit = order 10^5 microbial cells per sample (inadequate) so we must place limits on total microbial cell count (living and dead)
 - in work with science community consultants, and RSSB. Possible strategy:
 - 1) limit to order 5 [TBD] cells per sample*
 - 2) collect thorough genetic inventory and contaminant archive to facilitate rejection of any terrestrial hitchhikers

* as of 2014 cell detection limit in rock is $\sim 100/\text{cm}^3$ (Morono et al. 2014)

Mars 2020 Science Requirements



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Science-based requirements related to life detection and biosignatures:

5. Procedural witness blank strategy to characterize inorganic, organic, and biologic contamination occurring at and after ATLO. In work in consultation with OCP chairs and RSSB.



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Planetary Protection Requirements

Bernard

Project Approach to Planetary Protection (PP) Requirements



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- Supported Organic Contamination Panel as it evaluated organic contamination requirements
 - Panel recommended < 40 ppb total organic carbon and noted that cleaner is better
 - Defined Tier 1 compounds and recommended < 1 ppb for each
- Supported development of Level 1 requirements with Mars Exploration Program, Mars Program Office, and Office of Planetary Protection (OPP). Key Requirements:
 - Viable organisms per returned sample: < 1 (TBC)
 - Total Organic Carbon in returned sample:
 - Baseline: < 10 ppb (TBC)
 - Threshold: < 40 ppb
 - Tier 1 compounds in returned sample: <1 ppb
- Proactively developed architecture and wrote Project-level (L2) requirements based on Level 1 requirements and anticipated PP requirements associated with Category IVb *subsystem level* per categorization request
- Submitted categorization request update and supporting material in March of 2015 in response to PPO request
- Updated L2 requirements upon receipt of Partial Category Letter in May of 2015
- Support weekly telecons with OPP to understand product update requests and work through issues (based on OPP availability)
- Developed draft PP Plan and in process of responding to OPP requests for modifications and augmentation
- Personal Note: This is the third project in which this PSE has managed the planetary protection portfolio – including Juno, InSight, and now M2020

Project-Level (Level 2) Planetary Protection Requirements



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- In response to MSL lessons learned related to PP not being sufficiently integrated into the standard project structure, M2020 (following the InSight example) included a significant number of PP functional requirements in the requirements flowdown – starting at Level 2.
- Key Level 2 PP requirements include

Category	Number	Comment
Requirements similar to InSight Requirements or MSL practices	8	No issues
Witness Plates, Blanks, and Archiving	3	New, but not driving
Special Regions	3	One potential driver
Viable Organisms	1	Driver
Organic Carbon	1	Driver
PP Category	1	Driver

Driving Planetary Protection Requirements



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L2 Req #	Short Text	Paraphrased Requirement	Comment
72267	Anomalous landing, hydrated minerals, and Induced Special Regions	Analyze induced special regions caused by anomalous landing events that could bring RTG components in contact with hydrated minerals.	Driver, non-driver, or extremely restrictive landing depending on final wording
72267	Probability of viable Earth organism in returned sample	Probability less than the product of the total internal area and a surface bioburden limit of 0.03 viable organisms per m ² .	Per Partial Cat Letter. Allows ~ 0.0001 to 0.00015 as probability of viable organism per sample. Level 1s say <1 organism (TBC).
44380	Organic Carbon	The acceptable return sample Organic Carbon contamination levels are: <ul style="list-style-type: none"> Any Tier 1 compound (organic compounds as defined in the Contamination Control Plan): 1 ppb Total Organic Carbon (TOC): 10 ppb (TBC) 	For TOC, Level 1s say: Baseline: <10 ppb (TBC) Threshold: < 40 ppb
49387	PP Category	Category IVb implemented at subsystem level, as defined in NPR 8020.12D.	Expecting update to Level 1 noting Category V, will update L2s accordingly.



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Spacecraft and Sampling and Caching System Overview

Steltzner

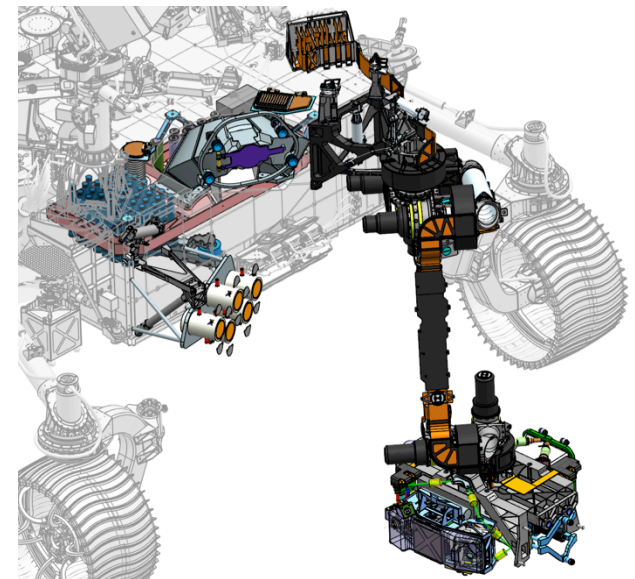
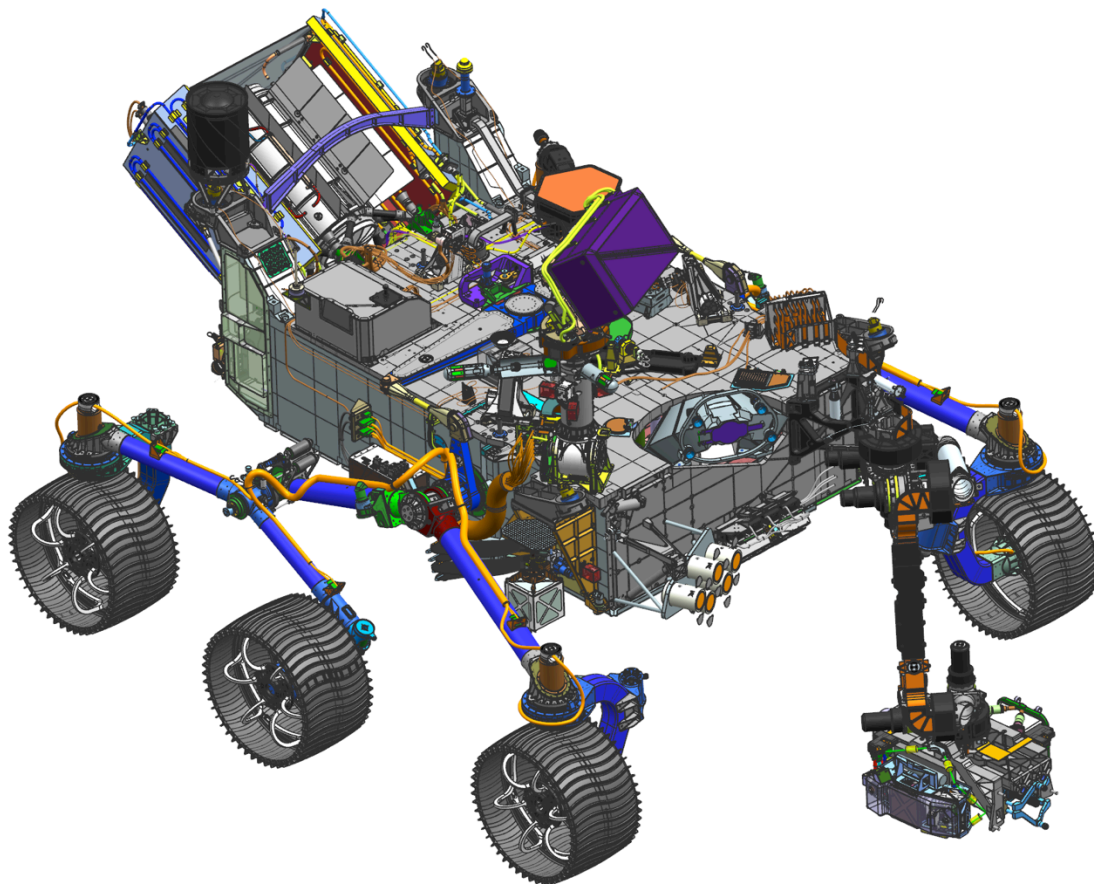
Mars 2020 Mission: Sampling and Caching



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Mars 2020 Sampling and Caching System (SCS) is responsible for acquiring and sealing samples of Mars for possible return to Earth



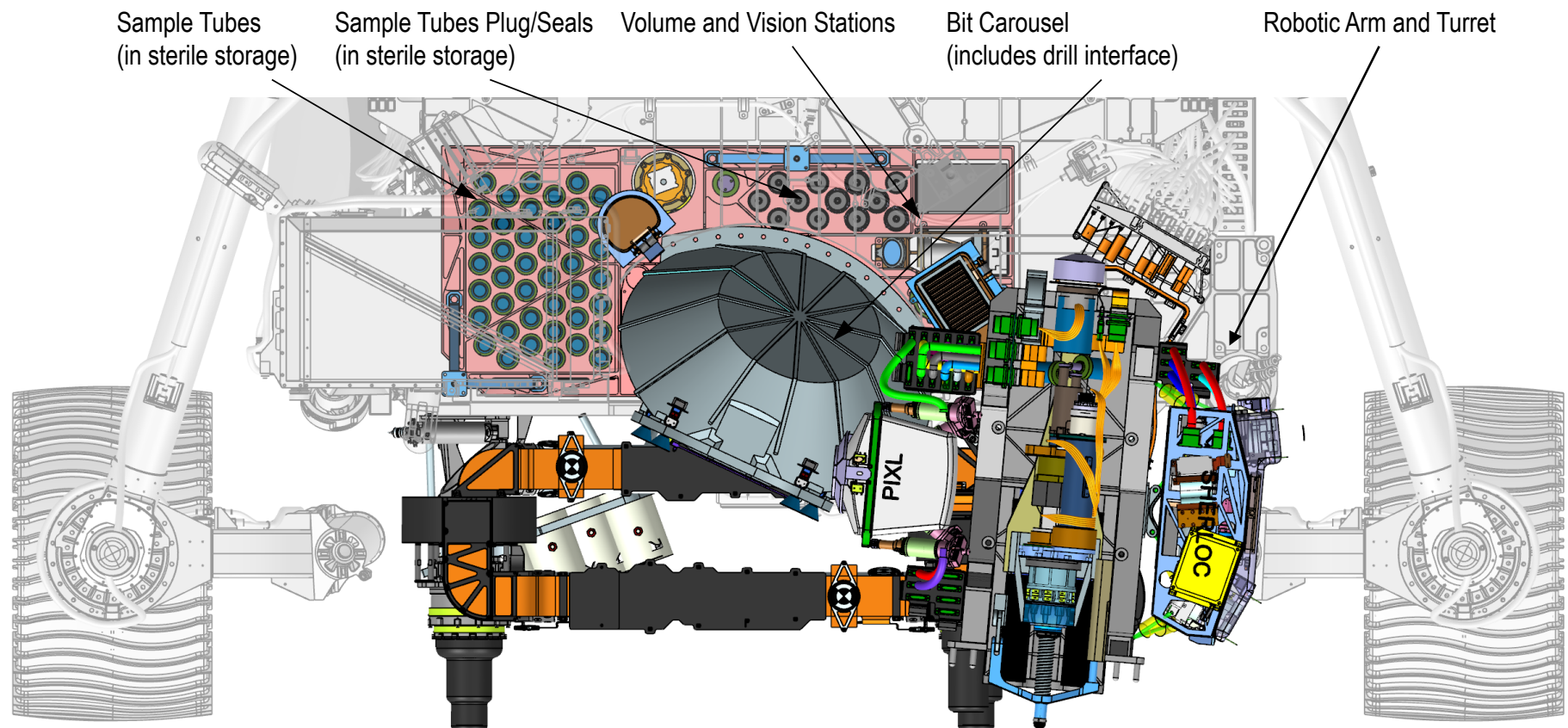
Hardware/Design Overview (1/3)



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- Sampling and Caching System Hardware

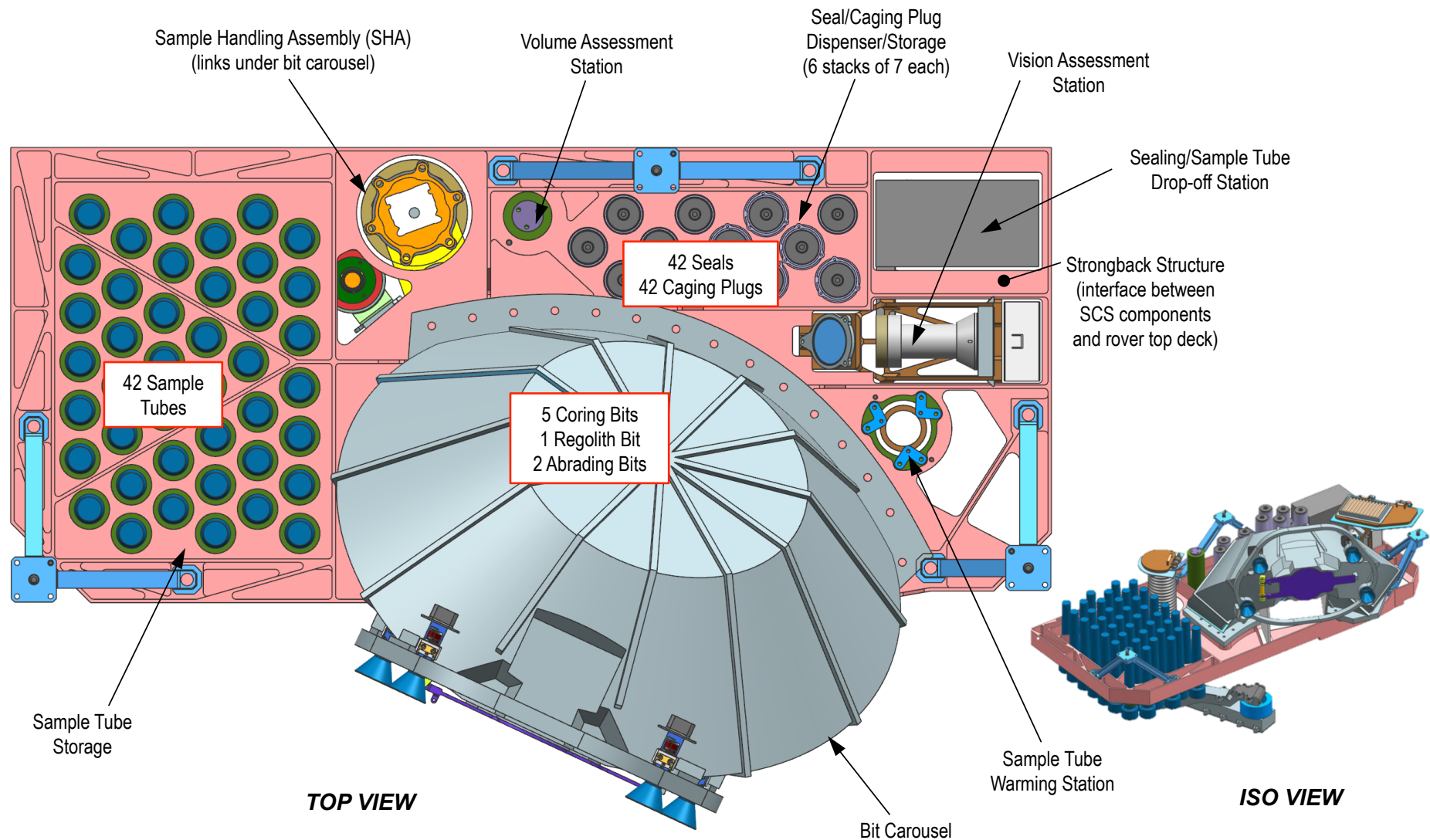


Hardware/Design Overview (2/3)



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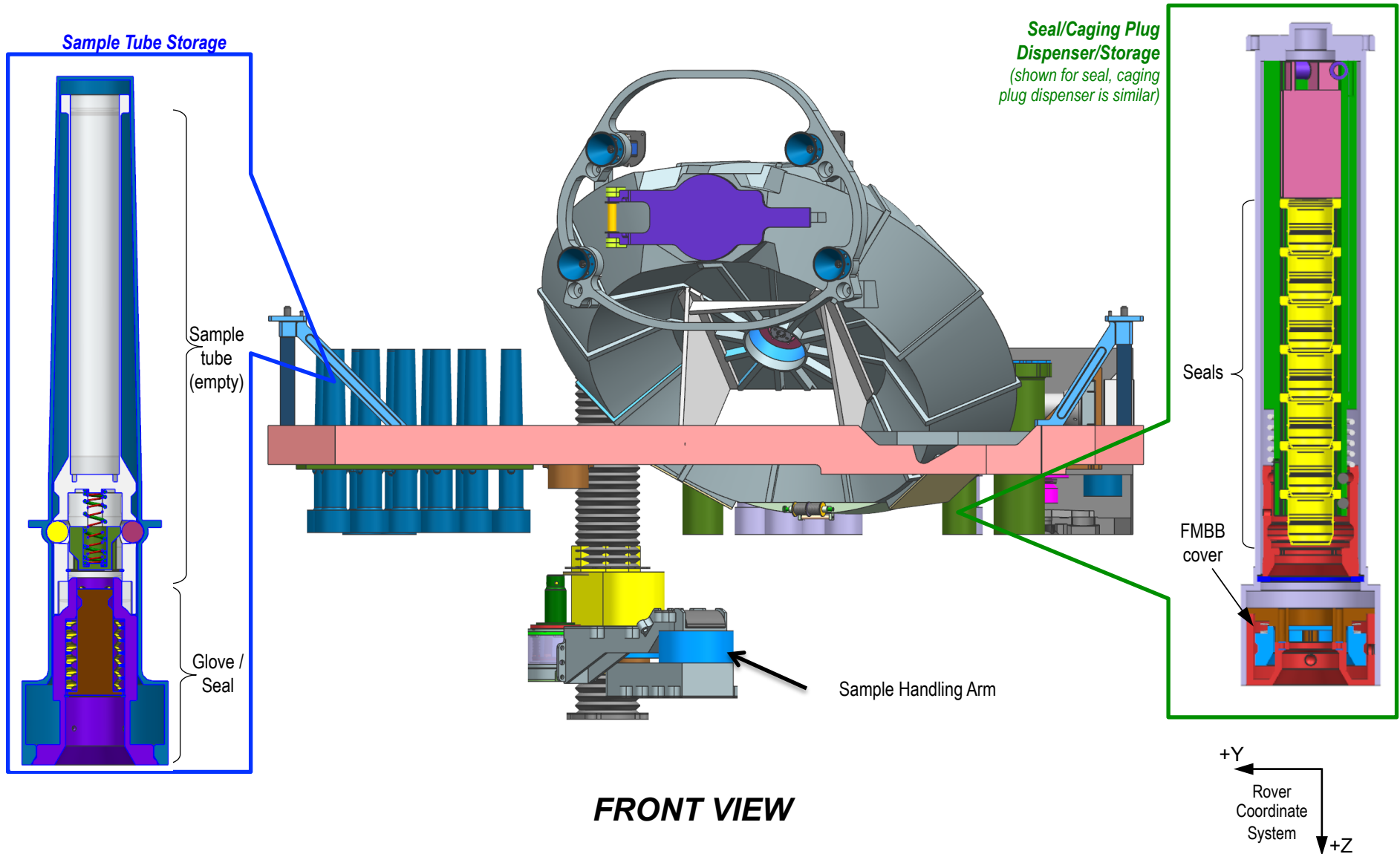


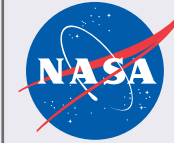
Hardware/Design Overview (3/3)



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Operational Flow (Movie)

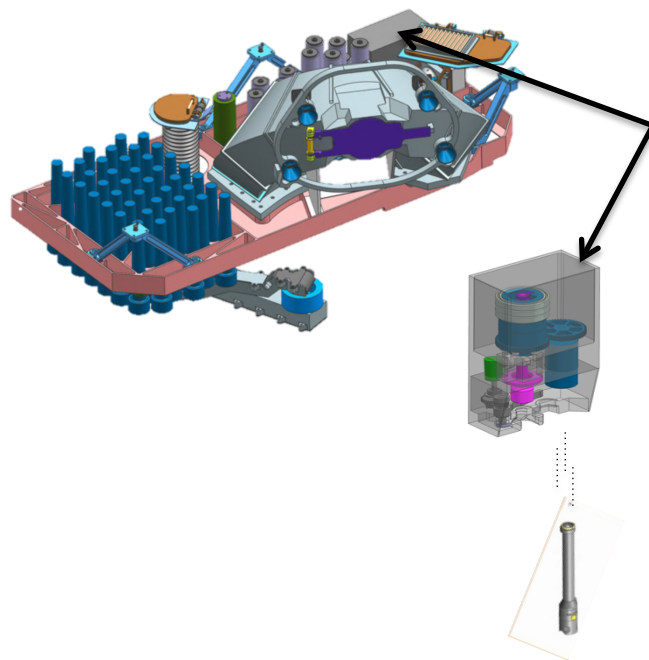
Sample Caching



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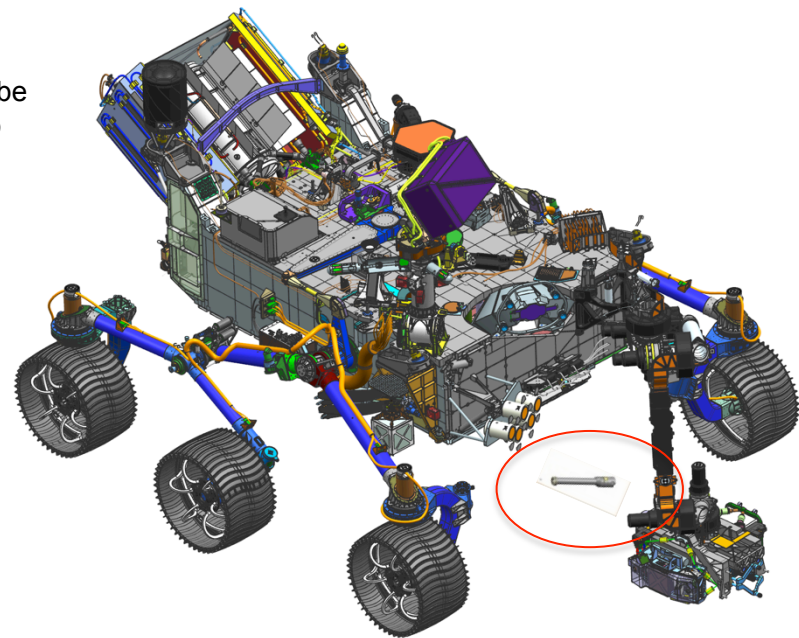
Mars 2020 Project

- The Mars 2020 project will cache the final collection of tubes on the Mars surface for later retrieval
 - Each tube is labeled for identification and sealed to protect sample
 - Cache is located for ease of retrieval by future mission



Sealing / Drop-off

- Axial load to seal tube
- Tube gripper acts to drop sealed tubes



Adaptive Caching Overview



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Mars 2020 Project

Adaptive Caching is the baseline approach for Mars 2020

1. Samples are drilled into tubes, tubes are sealed, and then stored on board the rover
2. At an appropriate location, samples (and blanks) are deposited together on the surface

There is no "cache container" that holds the samples

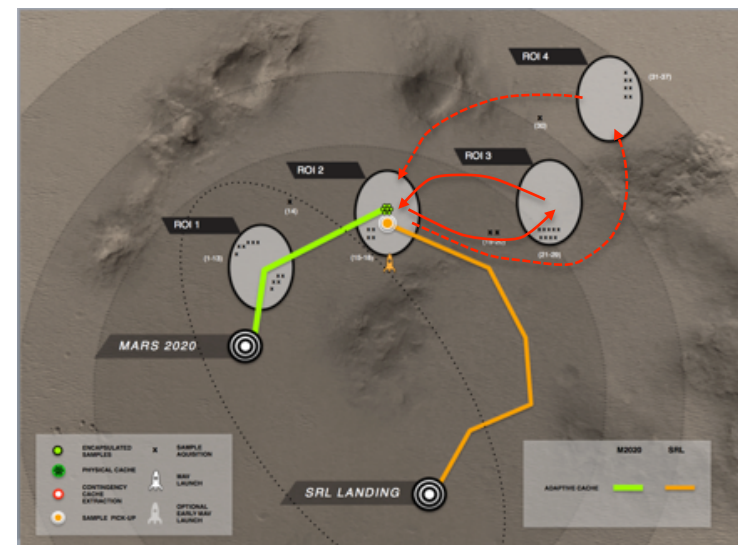
Tubes and seals designed to withstand >10 years on Mars surface

Advantageous for science

- Allows for continued sampling and caching after prime mission
- Offloading of samples reduces mission risk (and risk averse behavior) associated with traverse and other hazards
- Samples could be down-selected individually for Earth return long after the end of the Mars 2020 mission

Baseline operational assumptions for Adaptive Caching involve use of the *Depot Cache* operational scheme

- All sample tubes are deposited in a single location
- Location is determined to be accessible for the follow on retrieval mission
- Location is chosen to minimize joint mission risk across both the depositing and retrieving missions



Sample Tube Temperature



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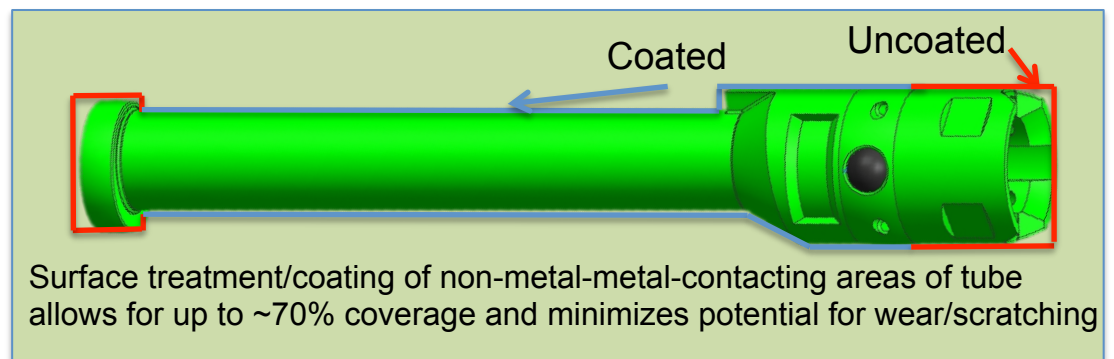
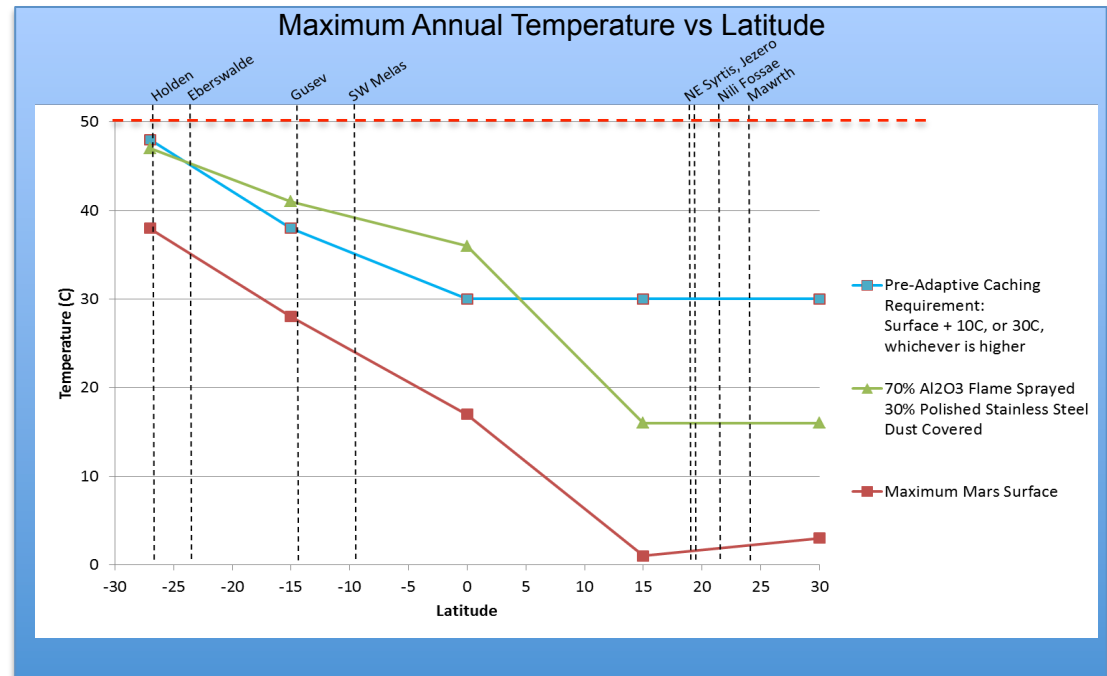
Mars 2020 Project

Assessment:

- Currently Mars 2020 project is assessing the sample temperature under a set of conservative assumptions
 - Low albedo surface assumptions
 - No thermal conduction to the surface
 - Conservative dust covered state
- Project is looking to coat sample tubes for high emissivity
- On going testing underway to confirm performance assumptions
- Science concern focuses most keenly on temperatures above 50C

Results:

- Sample temperatures under Adaptive Caching approach exceed the pre-adaptive caching temperature requirements by <10C at some latitudes
 - Maximum of ~5C exceedance at current set of landing sites
 - Meet requirements at most landing sites
- All forward paths likely to perform well below the 50C concern temperature.





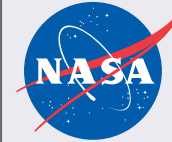
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Contamination Mitigation Approach and Work-to-Date

Steltzner

Mars 2020 Contamination Overview

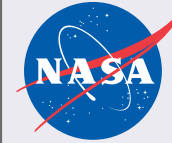


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- Mars 2020 uses an approach in which elements of the system which are in contact with the samples or have high risk as contamination sources are cleaned and retained clean
 - *Cleanliness is Organic, Inorganic and Biological*
 - *Hardware contamination threat determines level of cleanliness*
 - *Cleanest hardware is sterilized at 500C for minutes*
 - *Least clean hardware is maintained at $< 300\text{Spores}^c / \text{m}^2$*
- On Earth, Mars 2020 seals clean hardware away to prevent recontamination
- On Mars, we utilize contamination transport modeling to understand and quantify recontamination threat
 - *Leveraging common techniques used for molecular and particle transport for UV observation S/C*
- Mars 2020 believes that this approach is consistent with the “subsystem” approach found in 8020.12
 - *Such an approach manages the contamination gradient on Earth and at Mars in operations*

Mars 2020 Contamination Principles

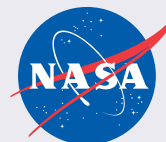


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- *P1: The Mars 2020 sterilized subsystems will be maintained sterile until needed for use in sample acquisition.*
 - *For dominant transfer surfaces (tube walls) the sterility is maintained in parallel (like a band-aid)*
- *P2: Period and breadth of exposure to possible contaminants is to be minimized*
 - *Samples are sealed against recontamination immediately after acquisition and until present in the sample handling facility.*
 - *Clean things shall not touch dirty things*
- *P3: Minimize the knowledge of the system and contaminants needed to ensure contamination performance*
- *P4: Manage off-nominal risk by minimizing the contamination sources via design and material selection*

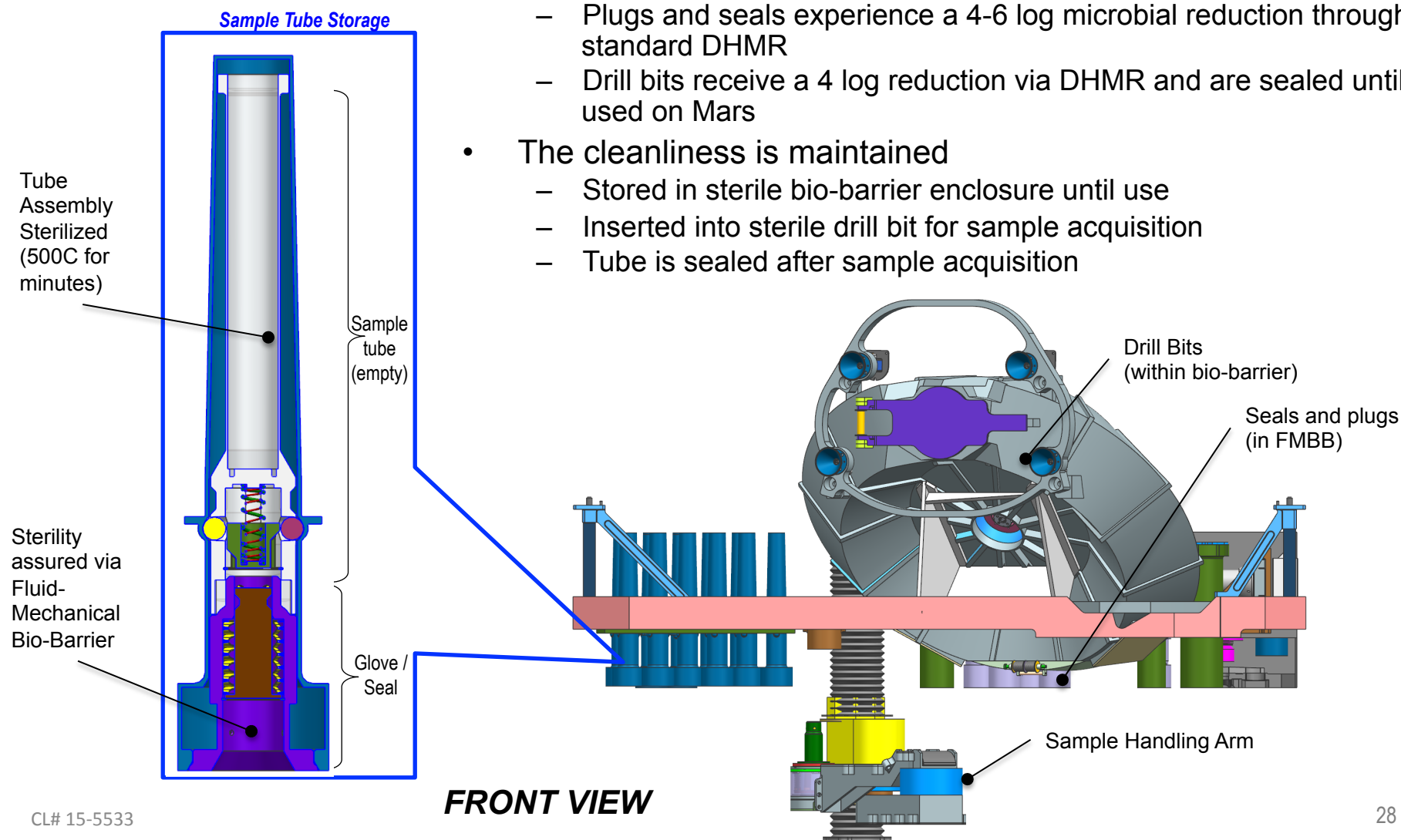
Planetary Protection Specific Hardware



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Mars 2020 Project

- The planetary protection *subsystem* is the sample tube
 - Tubes experience 12 log overkill microbial reduction at 500C
 - Plugs and seals experience a 4-6 log microbial reduction through standard DHMR
 - Drill bits receive a 4 log reduction via DHMR and are sealed until used on Mars
- The cleanliness is maintained
 - Stored in sterile bio-barrier enclosure until use
 - Inserted into sterile drill bit for sample acquisition
 - Tube is sealed after sample acquisition



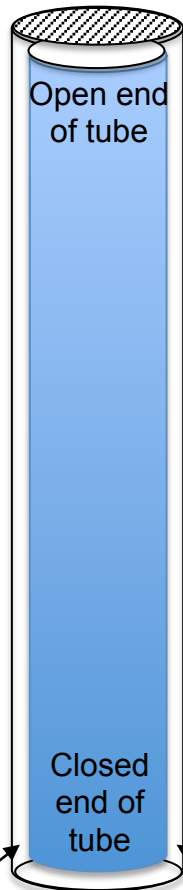
Barrier Based on Viscous Fluid Mechanics



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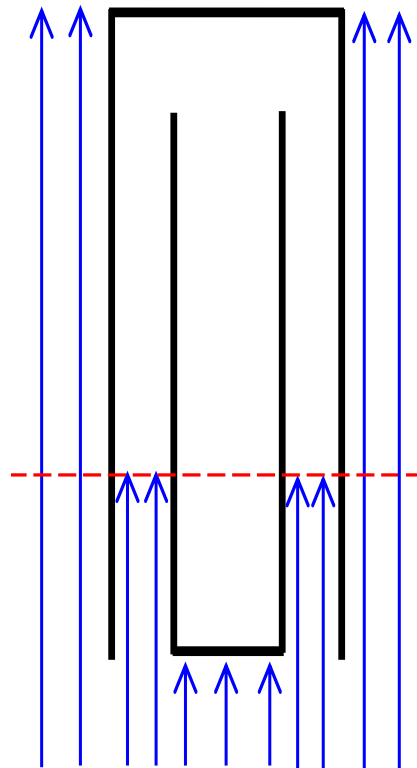
Mars 2020 Project

FMBB



Close clearances act as a Fluid Mechanical Bio Barrier

FMBB

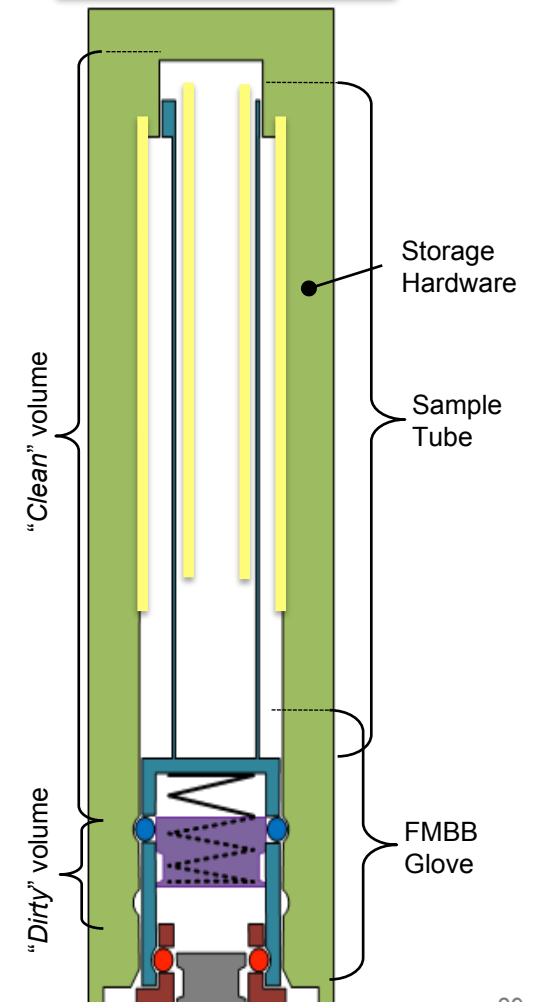


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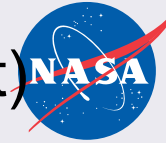
Test Tube



Sample Tube



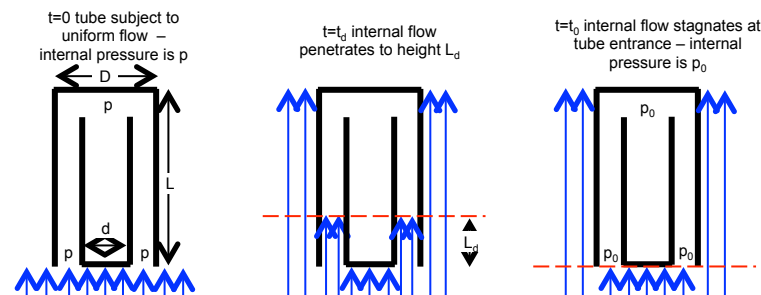
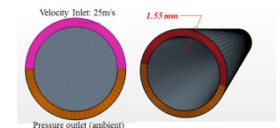
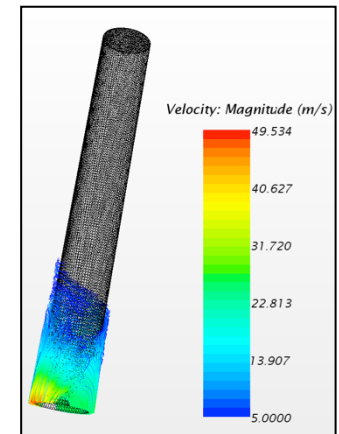
Barrier Based on Viscous Fluid Mechanics(cont)



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- FMBB uses viscosity and gravity to prevent particle transport deep into the sterile region of the sample tube storage
 - A gap of ~0.5 mm, and annular length of ~8mm thwart particle motions into the sterile region
 - These dimension are acceptable in terms of the robotic function of the device
- Use requires management of the pressure-rate experienced by the stored tube
 - ATLO Air-handling, Launch depressurization, EDL repressurization, etc.
 - Direct symmetric and bounding asymmetric external flow fields considered
 - Driving case is EDL heat shield separation flow disturbances
 - Device sized accordingly
- Hand analysis, CFD and DPS have been performed to assess design requirements and performance
- Expert review has occurred
- Test demonstration of FMBB function planned for early CY 16

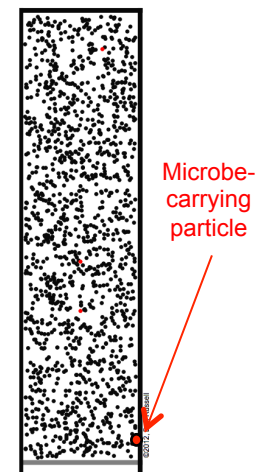


$$\text{Ideal Gas Law: } p = \frac{mR_g T}{V_t}, \quad p_0 = \frac{m_0 R_g T}{V_t} = p + \delta p \quad (\delta p = \frac{1}{2} \rho u^2) \rightarrow \frac{\delta m}{m} = \frac{\delta p}{p} \quad (\delta m = m_0 - m)$$

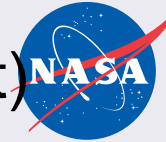
$$\text{Mass Conservation: } \frac{\delta m}{t_0} = \rho u A \Rightarrow t_0 = \frac{\delta p}{p} \frac{V_t}{u A}$$

$$\text{Flow Stopping Time: } t_d = \frac{L_d}{u}$$

$$t_0 = t_d \Rightarrow \frac{\delta p}{p} = \frac{V_d}{V_t} \quad (V_d = L_d A) \quad \text{or} \quad \frac{L_d}{L} = \frac{\delta p}{p} \left(1 - \frac{\rho}{\rho_0}\right)^{-1}$$



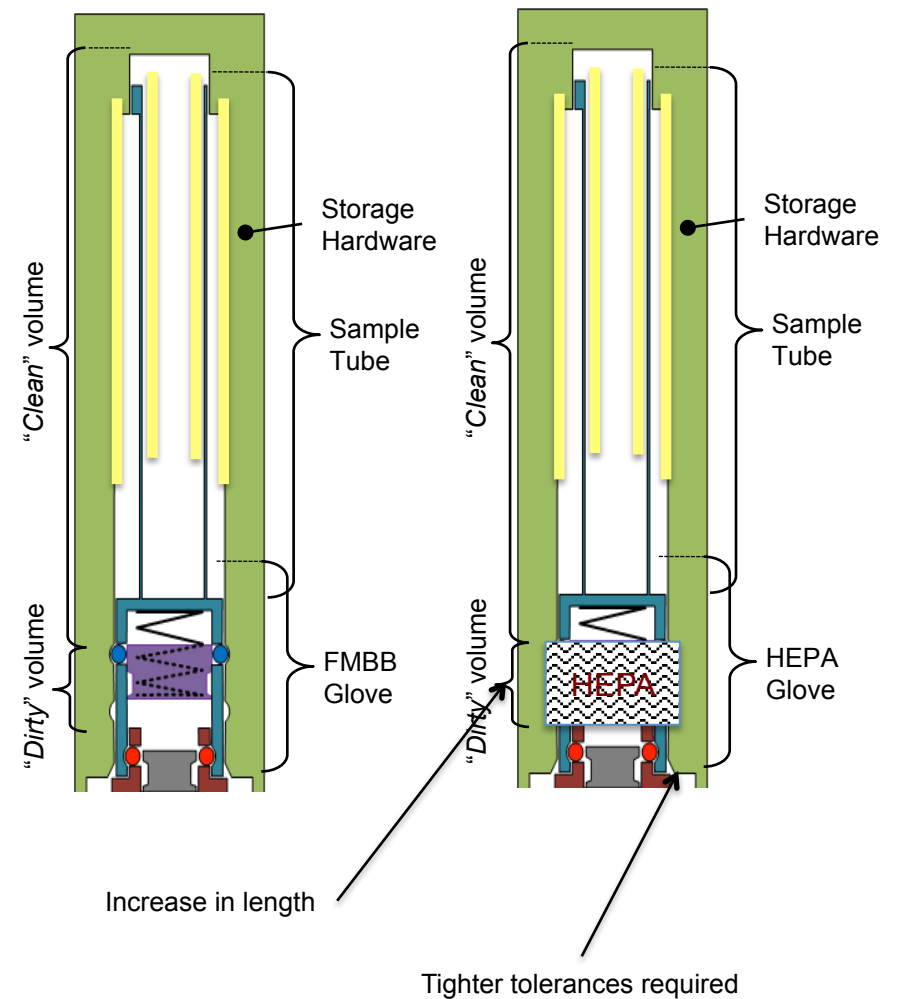
Barrier Based on Viscous Fluid Mechanics(cont)



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Mars 2020 Project

- A HEPA filter could be substituted in most locations in which an FMBB is used
 - Based on same physical principles
 - May result in longer tube storage length
 - Would increase molecular organic contamination
 - Requires tighter tolerance for mechanical mating surfaces
 - Results in greater mechanical risk to robotic functions
- FMBB is an ongoing engineering development with testing planned
- Off-ramp from FMBB-use to HEPA filter-use lies in the ~late CY16 time frame
- FMBB is preferred/baseline choice
 - Backup approach is HEPA-filter



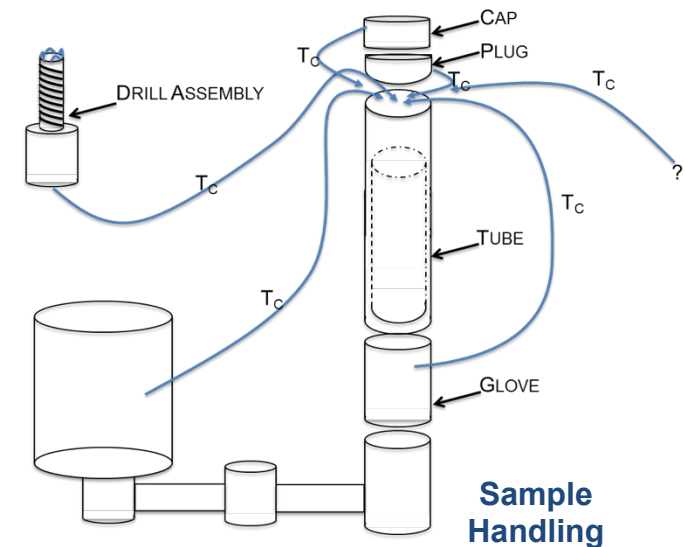
Operational Contamination Assessment



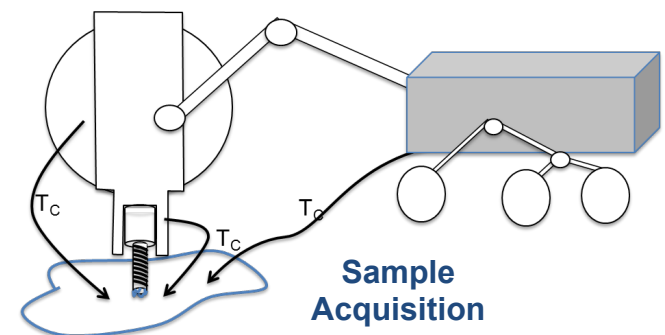
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- The at Mars transport threat is established and tracked by test derived / physics based analytical approach
 - Test derived or validated models
 - End-to-end performance analysis
- Analysis considers all sources from various elements of the spacecraft
 - Dominant source is rover
- There are several modes for liberation of particle contaminants
 - Contact transfer
 - Viscous fluid traction
 - Substrate vibration and acceleration
- We use test data to establish the physical conditions that result in liberation
 - Direct testing by project
 - Use of published test data



$$(TVO)_{final}^i = (TVO)_{initial}^i + \sum_{k=1}^n (TVO)^k T^{ki}$$



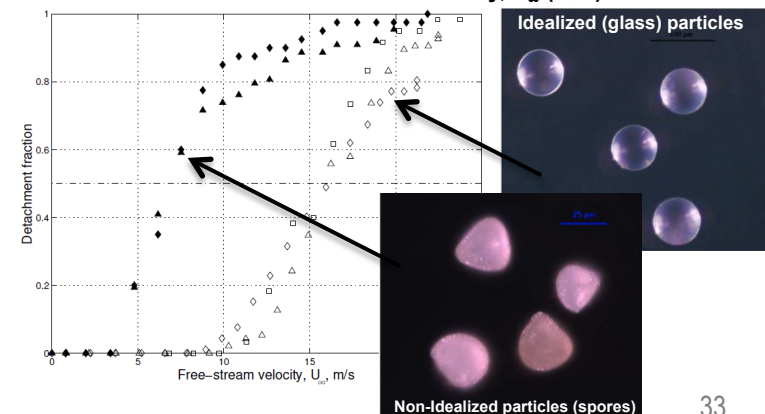
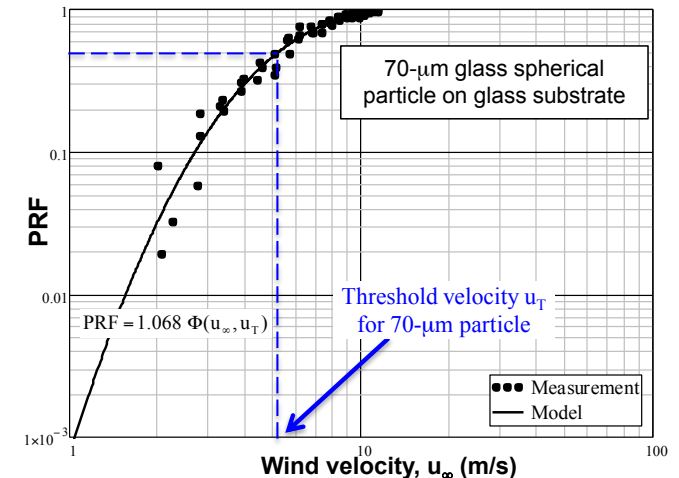
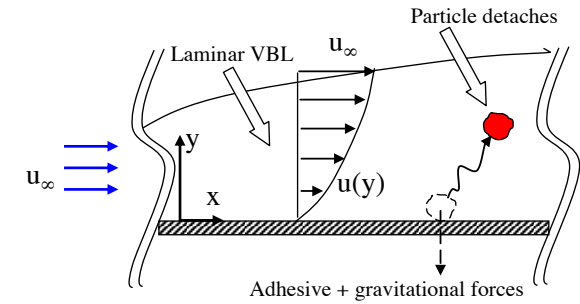
Liberation: Wind (viscous traction)



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Mars 2020 Project

- Wind-induced liberation model
 - Accounts for shear-flow forces acting on the particles in both turbulent and laminal viscous boundary layers (VBL)
 - Accounts for adhesion forces and surface roughness
 - Provides particle removal fractions (PRF) under wind conditions
 - Based on peer-reviewed literature.
 - Reproduces very well PRF for idealized particles (e.g. glass spheres on glass substrates)
 - Experiments at JPL provide model inputs for non-idealized particles (e.g. dust) are ongoing



- Liberation due to g-loads is based on semi-empirical model published in the peer-reviewed literature (J. B. Barengoltz, J. Spacecraft & Rock., 1989).
 - Model inputs for g-loads applied normal to the surface already determined (published).
 - Experiments at JPL that will provide needed input for tangential g-loads are almost complete.

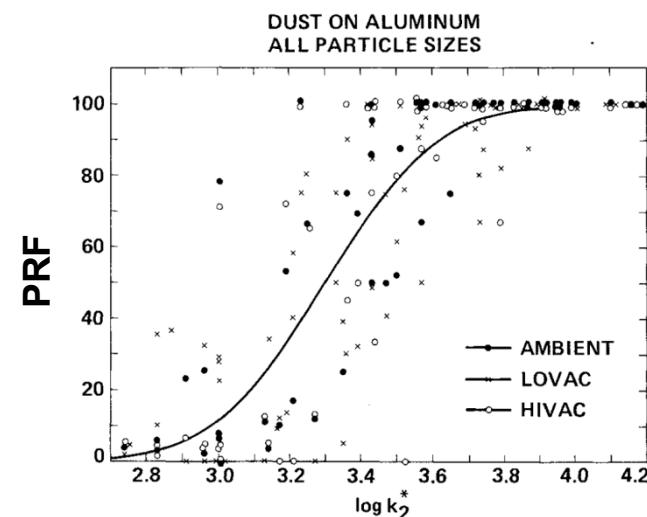
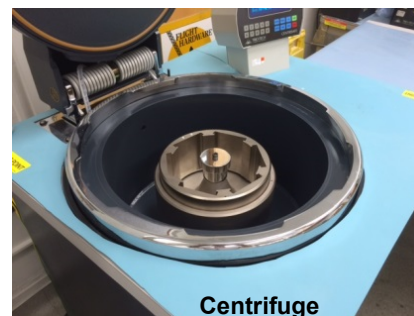


Fig. 13 Removal fraction as a function of $\log k_2^*$ [Eq. (7), $n = 2$] for dust on an aluminum substrate for all particle sizes and under pressure conditions indicated. Model per Eq. (3) with parameters $m = -3.30$, for ambient, lovac (10 Torr) and hivac (10^{-5} Torr); $\sigma = 0.25$.



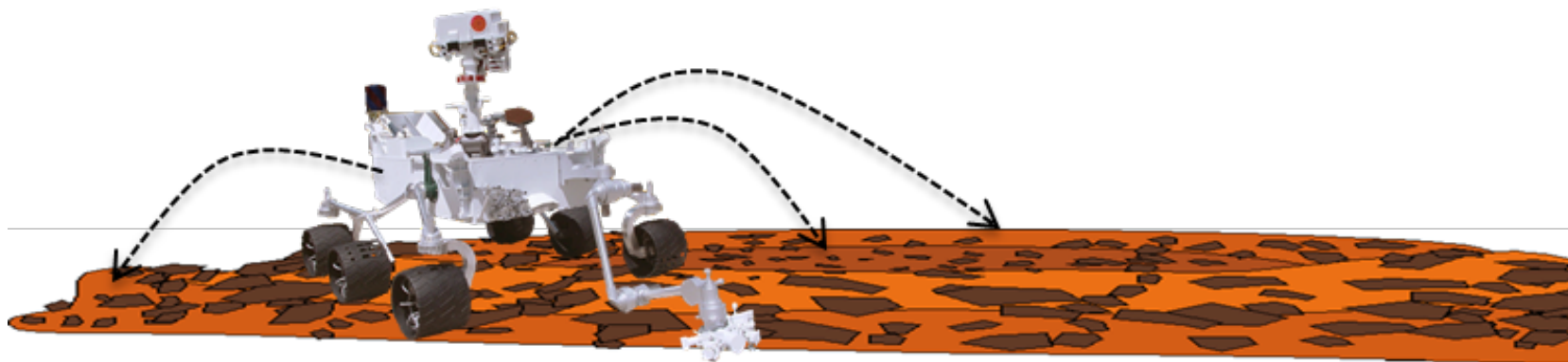
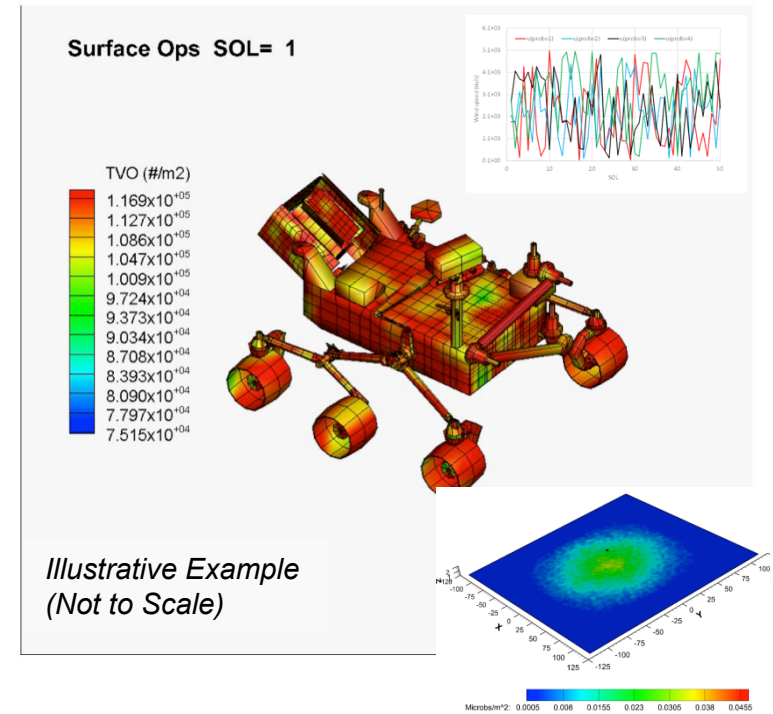
Wind Transport



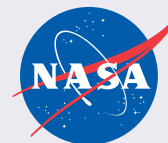
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- Numerical model under development that tracks particles under specified wind conditions
 - Applies re-suspension physics at rover surfaces
 - Solves equations of motion to yield distribution of contamination in areas surrounding the rover
- Such analytical tools are a key element of the operational contamination assessment



M2020 End-to-End Planetary Protection Performance



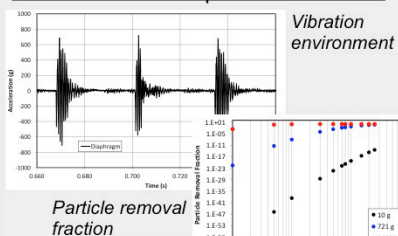
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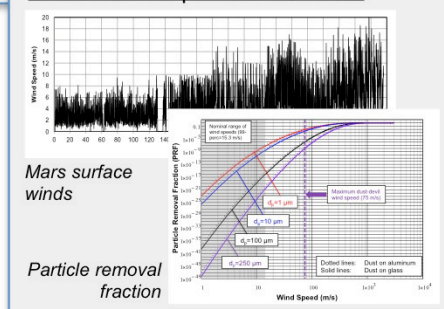
Particle Liberation

- Wind-induced
- Vibration-induced
- Surface contact

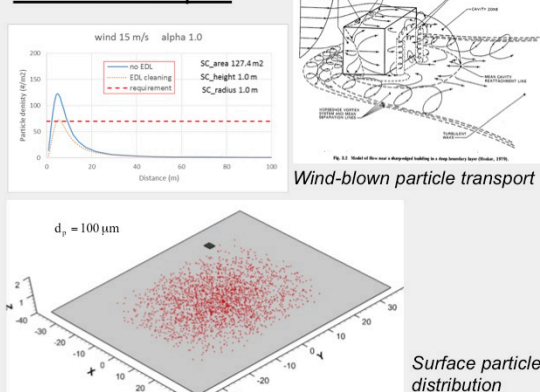
Vibration-induced particle liberation



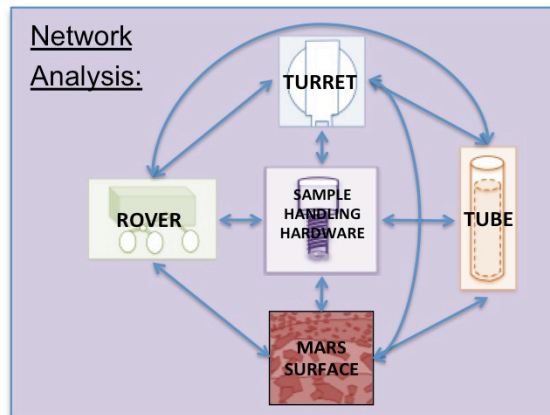
Wind-induced particle liberation



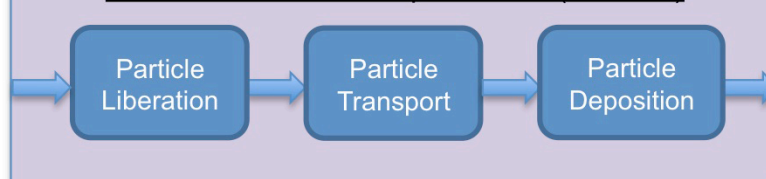
Particle Transport



Network Analysis:

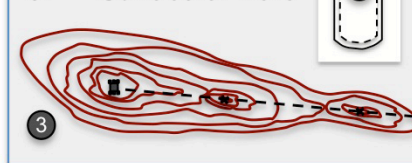


Microbial Particle Transport Model (Network)



Particle Deposition

1. Inside of tubes
2. Outside of tubes
3. Surface of Mars



SC = Surface Contamination event



Continuous models as function of time:

- $Ad(t)$ = particle adhesion vs. time
- $dm_{microbe}/dt$ = rate of growing/dying microbes

$F(t)$

Testing for Model Validation



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- Initiated model parameter validation testing and literature data mining
 - Resuspension under wind and mechanical loads
 - Extend particle type, size range
 - Surface roughness of real s/c materials

Particle Release by Wind Load

JPL-CIT Laminar Flow Cell: PRF Data

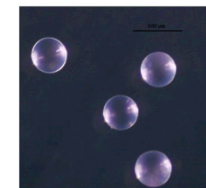
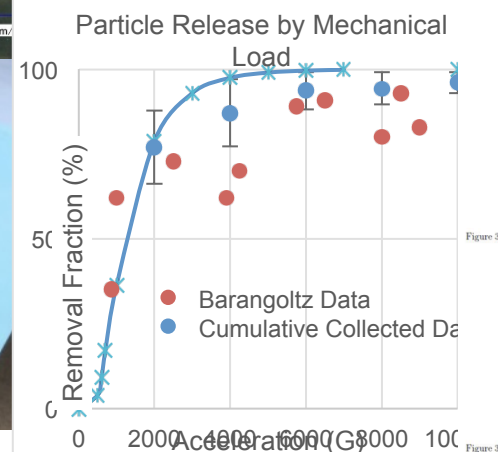
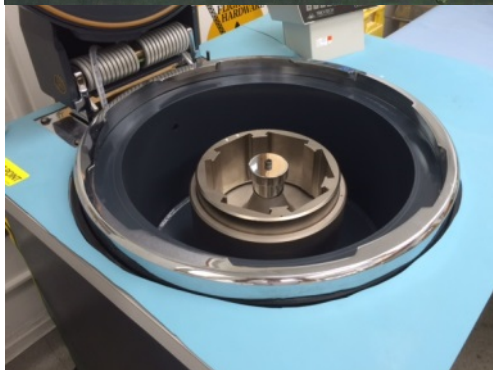
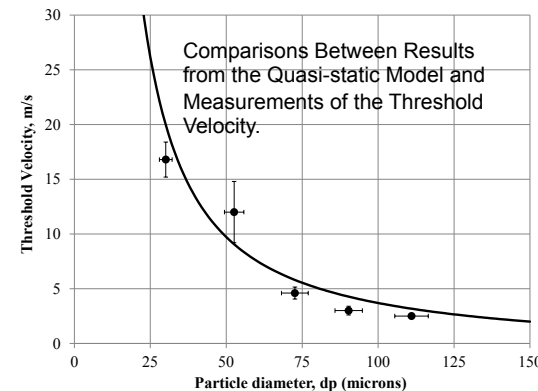
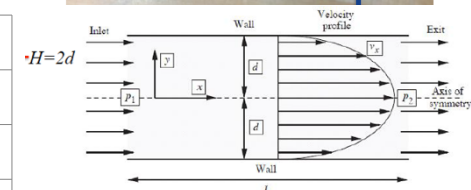
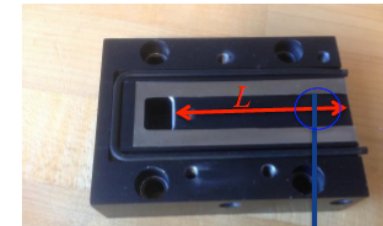


Figure 3.9: A close up of the GL32 microparticles taken with an Olympus optical microscope.

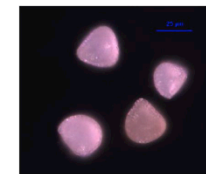
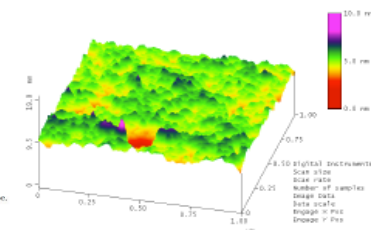


Figure 3.10: A close up of the LY30 microparticles taken with an Olympus optical microscope.



White Paint

Surface roughness S/C materials

CL# 15-5533

B103 Centrifuge Lab

Particulate Development Tests (Current Status)

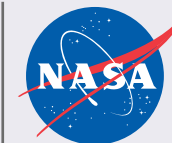


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Test	Supporting Tests	Status	Priority to reducing uncertainty in TVO in tube calculation	Level of difficulty	Planned execution period
FMBB demonstration	Particulate transport to tubes after firing. Demonstration on flight-like h/w in terrestrial environment/Mars-like environment	In Work	High	High: sensitivity of measurement	Q1 CY 16
Biological and abiological particle/surface PRF testing- Wind	Flow cell tests; Parameters: Velocity, temp, pressure, humidity, environmental cycling, surface roughness	Partially Complete	Medium Replicate published data to validate test set-up. Make new measurements of relevant particle sizes	High: Replicate Mars	Q3 CY15 – Q1 CY16 (initial)
Biological and abiological particle/surface PRF testing-Mechanical loads	Centrifuge particle adhesion tests. Parameters: g level, temp, humidity, environmental cycling, surface roughness	Partially Complete	High Replicate published data to validate test set-up. Make new measurements of relevant particle sizes	High: Replicating Mars environment	Q3 CY15- Q1 CY 16 (initial)
Measurement of microscale properties of rover surface (surface roughness)		Complete	High Measured parameter for model	Low	Q2 CY15- Q4 CY15
Saltation experiments		In Planning	Low-Moderate Residual particle dislodgment May not be required	Low	Q1 CY17

Molecular Development Tests (Current Status)

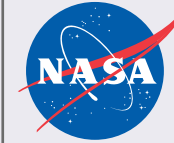


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Analysis	Supporting Tests	Status	Importance to reducing uncertainty in TOC in tube calculation	Level of difficulty	Planned execution period; Qs
Molecular transport to tubes after firing—ATLO & cruise	Demonstration on flight-like h/w in ambient & vacuum	In Work	Low (well understood)	Medium	Q3 CY15-Q2 CY16
Molecular to Tube @ Mars	Demonstration on flight-like h/w at 8 Torr	In Planning	Moderate (well understood)	High	Q4 CY 15-Q3 CY 16
Characteristics of outgassing against Tier-1	FTIR, DART-MS	In Work	High	Low	Q2 CY 15 – Q1 CY16
Characteristics of AC against Tier-1	FTIR, DART-MS, GC-MS	Completed Initial Testing	High	Low	Q2 CY 15 – Q1 CY16
Low energy surface coating	Molecular Desorption	Completed Initial Testing	High	Low	Q4CY 15 –Q2 CY 16

Biological Based Development Tests (Current Status)



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Analysis	Supporting Tests	Status	Priority to reducing uncertainty in TVO in tube calculation	Level of difficulty	Planned execution period
Fraction of airborne particulate w/ biological signature	BioVigilant	Complete	High	Low	Q3 CY15
Microbe to Particle Assessment on surfaces	Preliminary effort (underway) fixes particles and uses fluorescence	In Work	High	Low-high	Q1 CY16 – Q2 CY 17
Spore to TVO Assessment	Molecular and traditional microbiology enumeration of cleanroom samples	In Planning	Moderate	Medium	FY16-FY-17
Genetic Inventory	Metagenomic analysis of hardware and associated environment	Planned for Flight HW	Low	Medium	FY17 on
Microbial Adhesion on Surface	See wind and mechanical loads testing in particulate test table				

Peer and Expert Review To-Date



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- Several peer reviews and an extensive literature review have been performed.
- We have been in direct communication with the following experts in the field of particle resuspension
 - Professor Rick Flagan, Caltech
 - Dr. Costas Tsouris, Oak Ridge National Laboratory & Adjunct Professor, Georgia Institute of Technology
 - Professor (Emeritus) Patrick Dunn, Notre Dame University
 - Professor Abdelmaged Ibrahim-Essawey, American University of Cairo
 - Dr. Jean-Pierre Minier, Electricite de France (EDF)
 - Dr. Christophe Henry, Institute of Fluid-Flow Machinery, Polish Academy of Science, previously with Institute of fluid-flow machinery, EDF R&D
- We have performed extensive literature review on particle resuspension under wind and mechanical loads in the last five decades (1960s-2015)
 - Example: Review Article by Christophe Henry, Jean-Pierre Minier, “Progress in particle resuspension from rough surfaces by turbulent flows,” *Progress in Energy and Combustion Science*, Volume 45, December 2014, Pages 1-5
- Over 300 references on the topic have been reviewed and data synthesized into current plan
- PP Approach Independent Assessment Reviews (March & Oct 2015)
 - Mars Program convened
 - P. Christensen (ASU) – Chair
 - M. Meyer (NASA MEP) – exec sec
 - J. Allton (JSC)
 - B. Clark (SS)
 - M. Hagopian (SRB member)
 - J. Rummel (ECU)
 - A. Steele (Carnegie)
- PP/CC Institutional Assessment Rev. I, Rev II (Sept. 21, Sept 26, 2015)
 - Evans, Jordan (JPL) – Chair
 - Brace, Richard (JPL)
 - Fradet, Rene (JPL)
 - Lee, Gentry (JPL)
 - Tim O'Donnell (JPL)

Test Timing



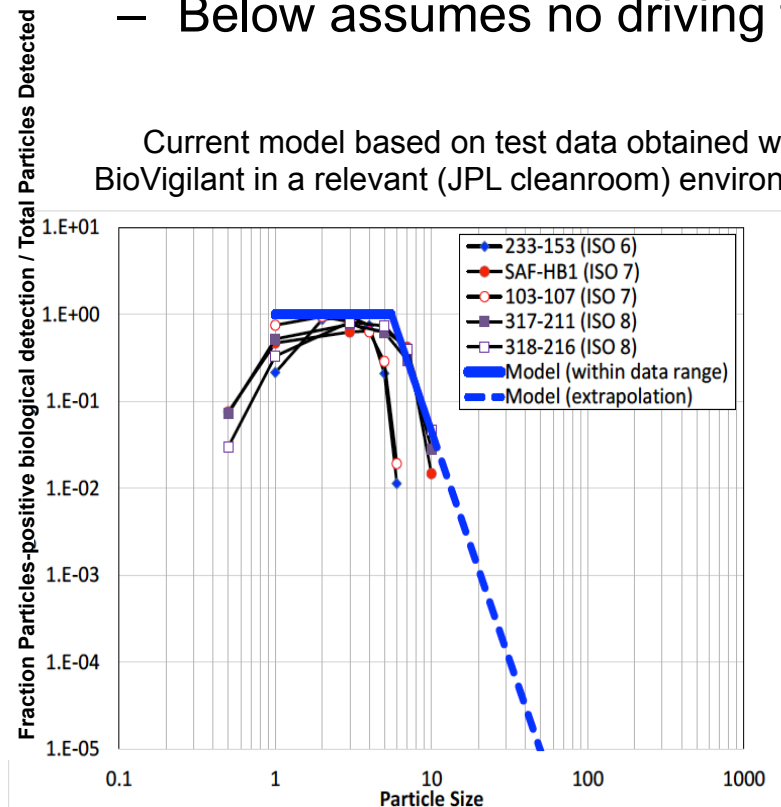
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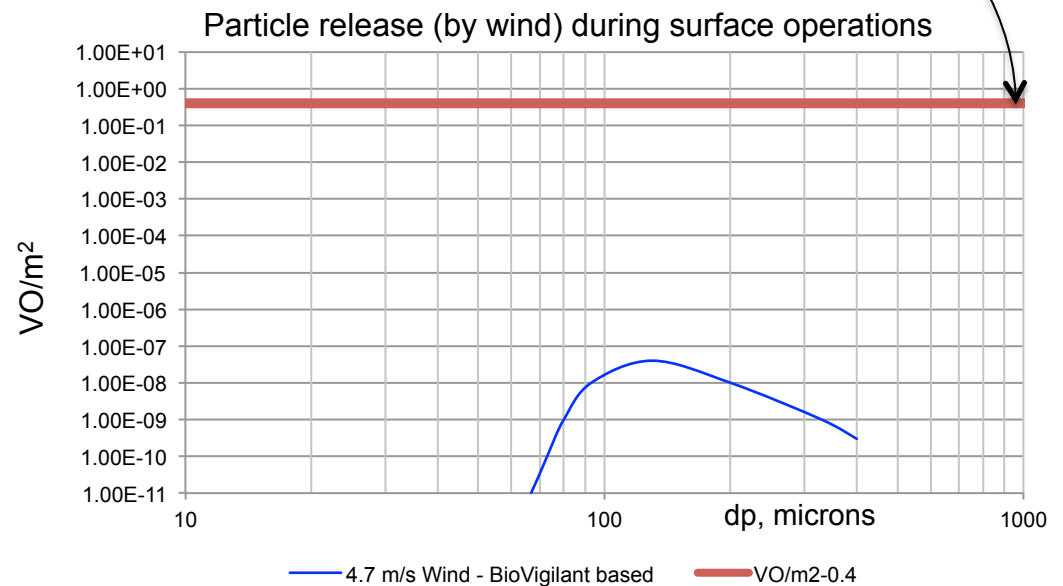
- Preliminary Christensen board report (October Review) suggests concerns
 - Regarding timing the planned tests
 - Regarding cost and schedule being incorporated into project plan
- Project has staffed up in FY16 to facilitate acceleration of high-priority testing (FMBB in particular)
 - Continuing to assess model using conservative assumptions until testing is completed and reviewed
 - Hardware options (HEPA) exist as design off-ramps
 - Testing to demonstrate FMBB efficacy is timed to allow use of alternate design if required
- Project's cost & schedule were updated in summer 2015 with all testing now in the baseline plan
 - Project is allocating significant reserves (60%) to the PP/CC area to be used if necessary
- Project is planning to provide updates in these areas to the JPL Institutional Assessment board, and the PPAIAR (Christensen) board prior to Project PDR in early Feb.

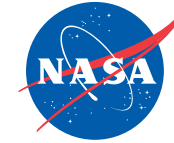
- Driving case is currently indirect contamination via Mars surface
 - Results shown assume no UV kill
 - Assume full @launch bio-burden
 - Worst case is nominal surface winds that do not move particles farther
 - Below assumes no driving from the commissioning position

Current model based on test data obtained with BioVigilant in a relevant (JPL cleanroom) environment.



VO/m² requirement to meet the 10⁻⁴ VO / tube PP requirement





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The Requirement for Operational Transport Analysis

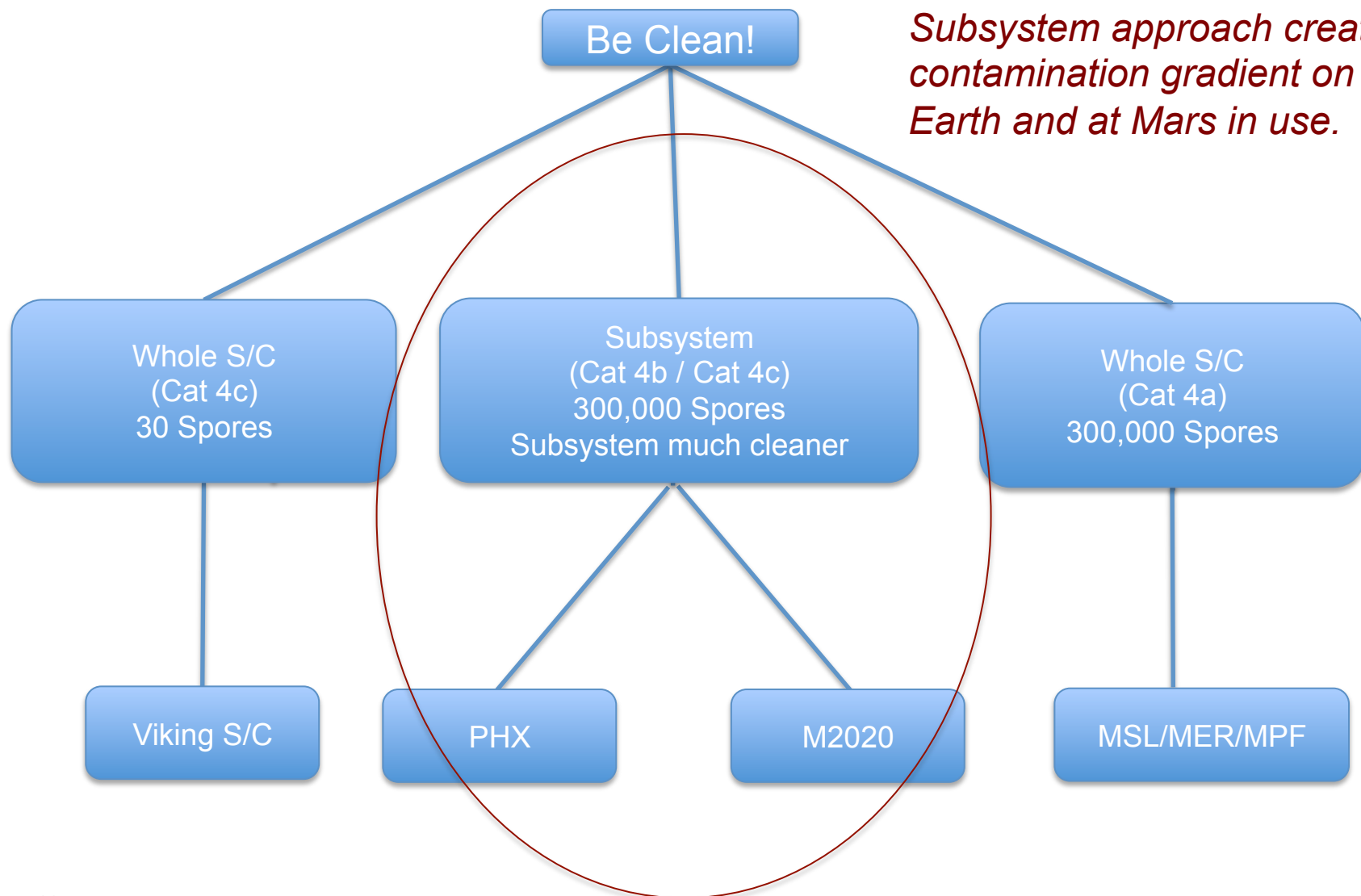
Steltzner

Biological Cleanliness and Architecture



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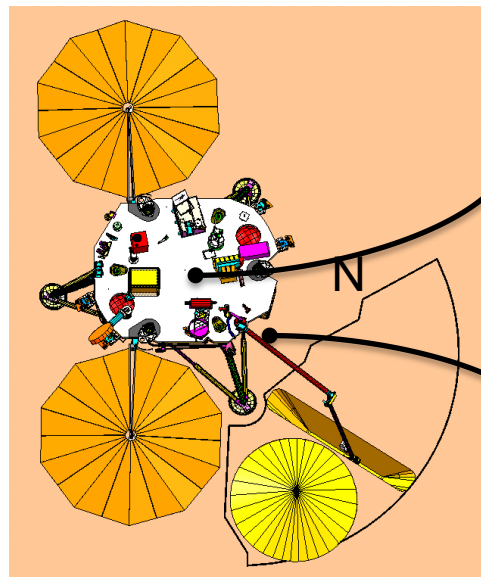
Operational Contamination Analysis: PHX



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- PHX used a fluid mechanical bio-barrier (HEPA Filter) to maintain cleanliness through ATLO, launch and landing
- Once in operations that bio-barrier was opened
 - Resulting in a contamination gradient on Mars
- It is useful to look at an example of a PHX like S/C configuration

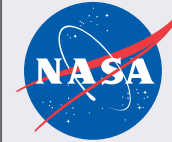


4a S/C Hardware:
 $\sim 6 \cdot 10^8$ VOs at Mars

**Biological Contamination
Gradient**
Amount Transferred \rightarrow ????

4b Subsystem Hardware:
 ~ 0 VOs at Mars

What is the Transfer from the S/C to a PHX-like Trench?



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- It is not enough to control contamination here on Earth and through cruise, we must have a model for contamination during operation at Mars!
- Consider two models:
 - Simple redistribution over the s/c and arm reach area (conservative?)
 - $150(10^6)$ VO on reachable area of arm
 - **$> > 10^6$ VO in trench!**
 - All the VO are blown clear of the vehicle during EDL and die from UV exposure on the way to the surface (not conservative?)
 - **0 VO in trench**
- We need more science/engineering brought to bear on the question of *operational transport analysis*
- Mars2020 is obligated to do such analysis
- *There is no 8020.12D subsystem approach that does not require such analysis and for which the contamination transfer results do not hinge on such analysis*

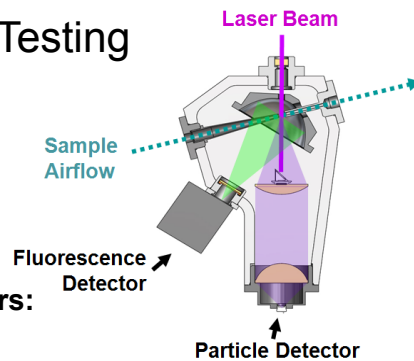
Operational Transport Analysis Required



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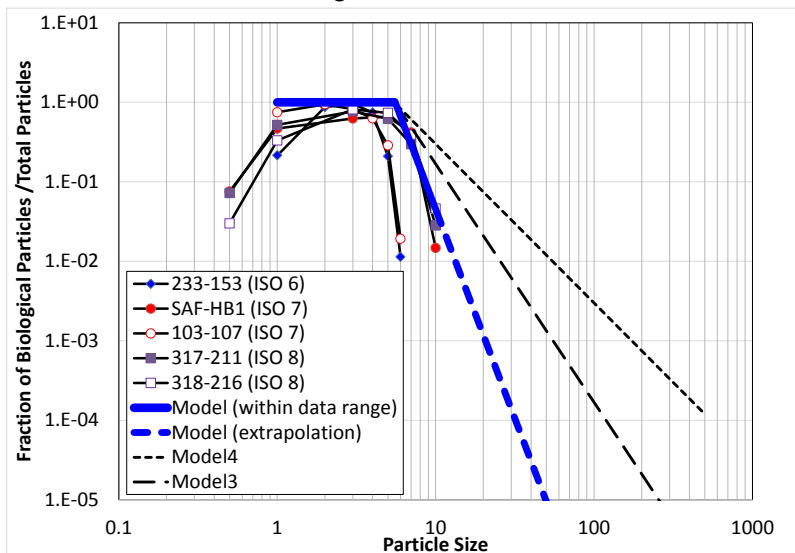
JPL BioVigilant Testing



Biological Markers:

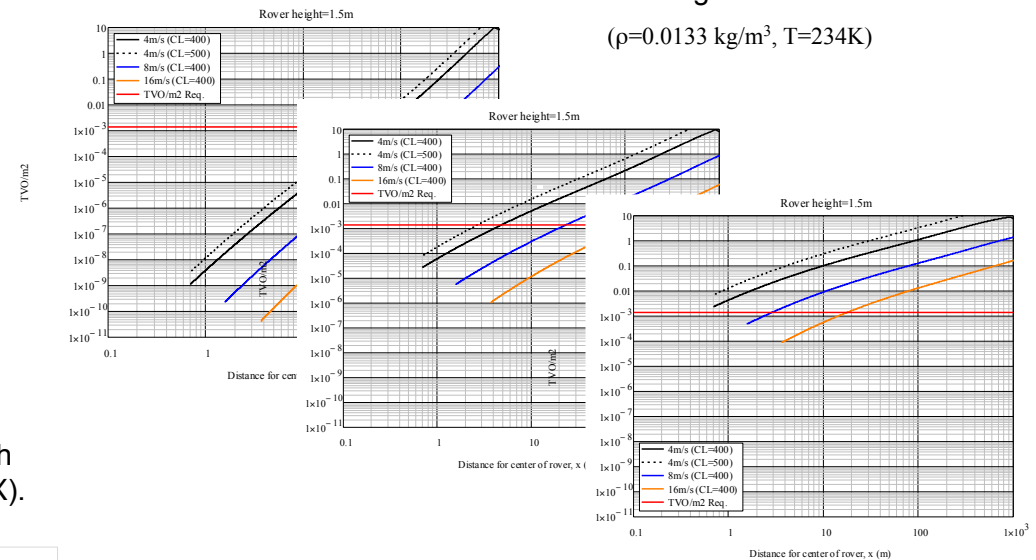
- 1) Riboflavin
- 2) NADH
- 3) Dipicolinic acid DPA (spore-specific)

TVO/particle based on BioVigilant data, scaled to match bioburden of 3×10^7 TVOs/m² (300,000 Spores ® on PHX).
Scaling factor = 1.588

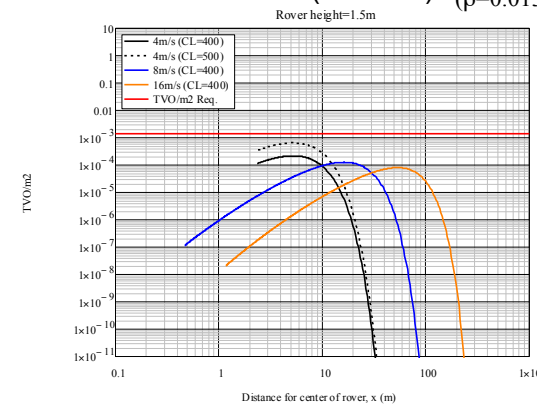


Assumes ALL particles come off at altitude of 1.5 m and NO EDL cleaning has occurred

($\rho=0.0133$ kg/m³, $T=234$ K)



Assumes particles come off at altitude of 1.5 m after taking into account adhesion forces (glass on glass); NO EDL cleaning has occurred (model 3) ($\rho=0.0133$ kg/m³, $T=234$ K)



CL=particle cleanliness Level



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Why Don't You Use PHX Approach?

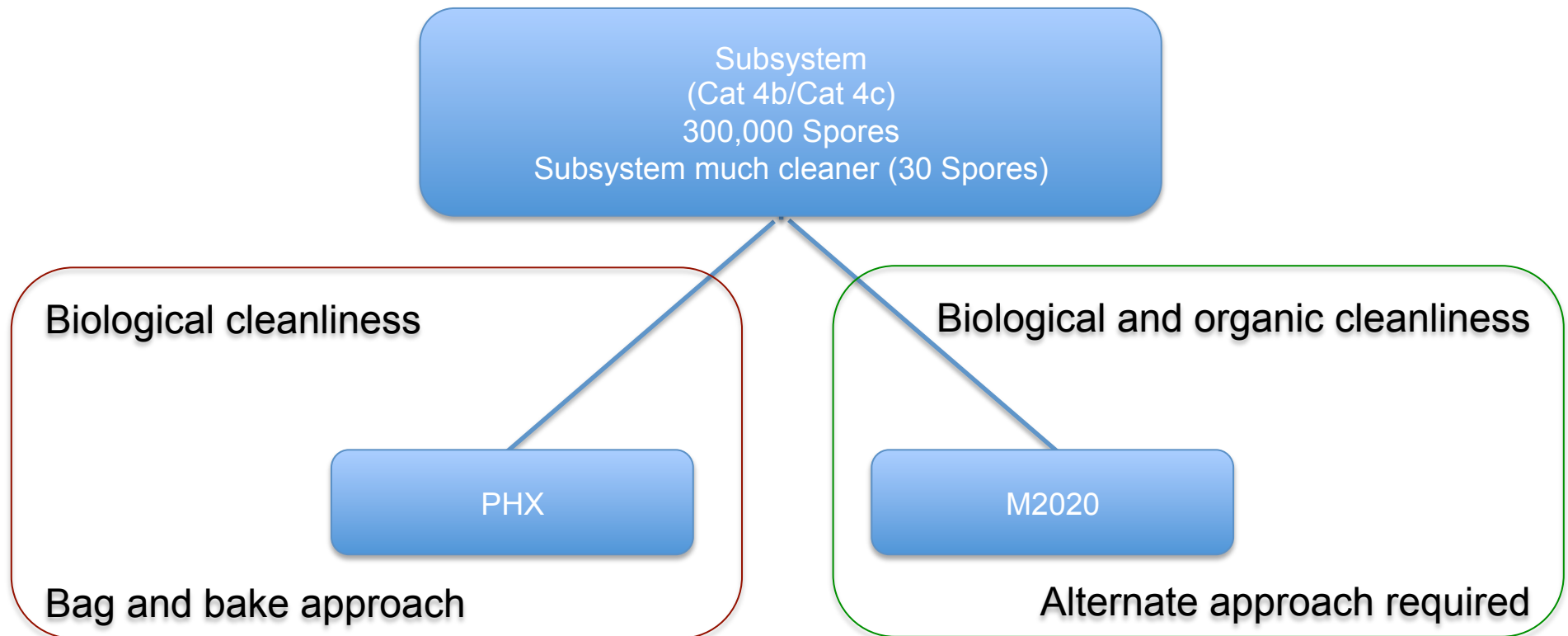
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Subsystem Architectures



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Mars 2020 PP Requirements (subset):

- 1.) Probability of a viable terrestrial organism , 10^{-4} per tube
- 2.) Total Organic Carbon < 10 ppb per sample
- 3.) Tier 1 organic compounds , < 1 ppb sample

SCS Enclosure Bakeout/DHMR

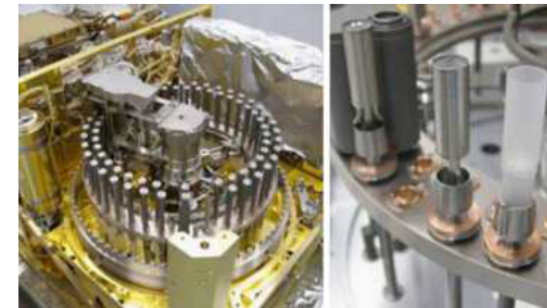


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How long would we need to bakeout the handling arm and other components in the enclosure to maintain tube cleanliness?

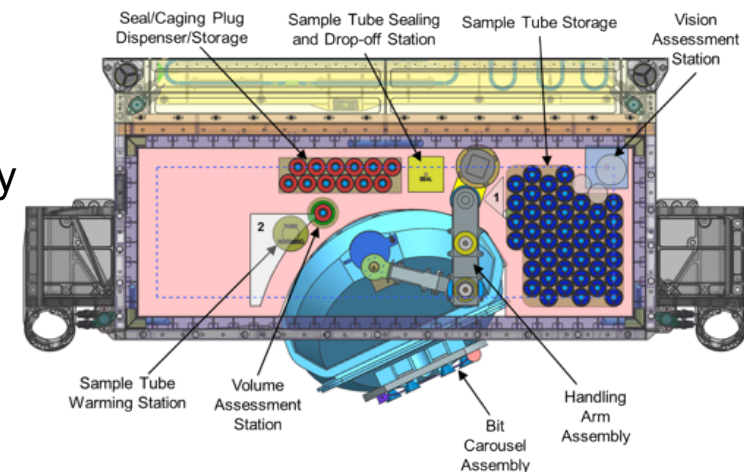
- Assume SCS roughly similar to SAM SMS
 - SAM SMS outgassing source rate: $1\text{E-}14 \text{ gm/cm}^2\text{-s}$
 - Very clean by S/C standard ($\text{MSL} = 1\text{E-}13 \text{ gm/cm}^2\text{-s}$)
 - SMS subassemblies [baked-out] until they reached the $1\text{e-}14 \text{ g/cm}^2$ rate.
 - Bakeout times ranged from 6 weeks for motors to 3 to 4 days for other items.
 - The entire assembly was baked at 90 for a week. (T. Errigo, personal communication)
- Applying that rate to a M2020 DHMR time ~100hrs
- Resulting Surface contamination to tube:
 - **$>200\text{ng/cm}^2$ ($>40\text{x}$ requirement)**
- To remedy the above, lengthen the CC bake-out by 40x (this is an unconservative assumption as outgassing decreases with time)
 - **Bake-out duration is 240 weeks (4.8 years)**
 - Such a duration is not practical



<http://link.springer.com/article/10.1007/s11214-012-9879-z/fulltext.html>

Fig. 5

The *left pane* shows the SMS integrated to SAM and the *right pane* shows both metal and quartz cups on the sample carousel





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Why Don't You Use Viking Approach?

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Flight System Tolerance to DHMR



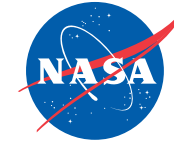
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- DHMR is problematic for a number of common materials and parts, notably*:
 - Electronics components: e.g., microcircuits, semiconductors, inductors, etc.
 - RF Applications: RF switches, RF filters, SMA connectors, Coax cables
 - Common materials: tie down materials, waxes, seals, adhesives & potting compounds
- Flight system components that cannot currently tolerate DHMR*:
 - Batteries
 - Telecom: SDST, SSPA
 - GN&C: IMU, Star Scanner
 - Pyros
 - Propulsion Components: valves, transducers, tanks, etc.
- M2020 unique components that cannot tolerate DHMR:
 - PIXL: high voltage power supply, optics, indium seal, tube
 - SHERLOC: optics
- MMRTG
- Facilities do not currently exist for system-level DHMR (cost estimate for new facilities ~ \$28M*)
- Lead times for attempting to develop DHMR compatible hardware would far exceed available development time on M2020

**Based on "Mars System Sterilization
Study Report," JPL-D-34992, 30 July 2006*

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How Much Contamination Gradient Does Mars 2020 Have?

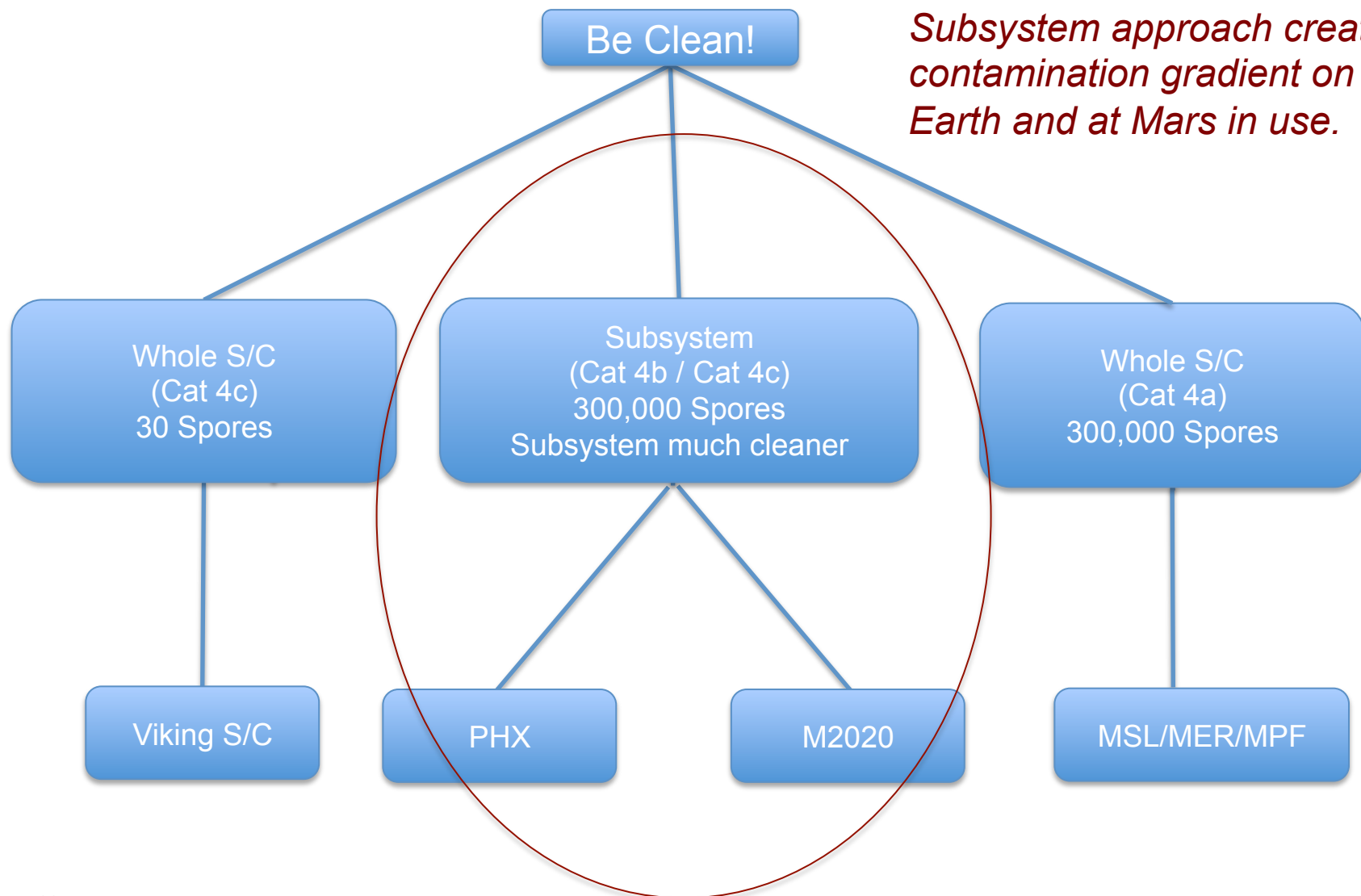
Steltzner

Biological Cleanliness and Architecture

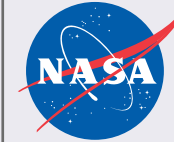


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What Is The Contamination Load?



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	Rover at Large	Turret + Arm	Sample Handling Enclosure
MSL @ Launch	20.5 k Spores ^c		
M2020 Requirement @ Launch	40 k Spores ^c	~2000 Spores ^c	~600 Spores ^c
Launch Terrestrial Viable Organisms	40k*1000 = 40M VO	2M VO	600k VO
Cruise disinfection	0.2X	0.2X	0.2X
@ Entry Organisms	8(10)⁶ VO	4(10)⁵ VO	1.2(10)⁵ VO

EDL Wind Cleaning (1/2)



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- Biological particles and abiotic particles share similarities and possess differences
 - Discussion with Army Aerosol Sciences branch suggest biologics have capacity for greater adhesion given similar geometries to an abiotic
 - Irregular geometries adhere more poorly than spheres or ellipsoids
 - Biologics may possess “will” – the ability to change their adherence state
 - Both biologics and abiotics adhere more in higher humidity environments
- Upon entry S/C is drier than on Mars
 - 7 months of hard vacuum
 - Bottom of rover and mobility is also colder than it will be on Mars
- During EDL, in this dry and cold condition the S/C surfaces are exposed to wind magnitudes that are above those seen on the surface
 - Max wind: 15.3 m/s 3- σ (measured)
 - Max Dust Storm: 40 m/s (hypothesized)
 - Max Dust Devil: 60 m/s (hypothesized)

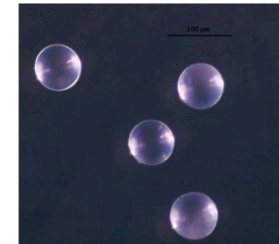


Figure 3.9. A close up of the GL32 microparticles taken with an Olympus optical microscope.

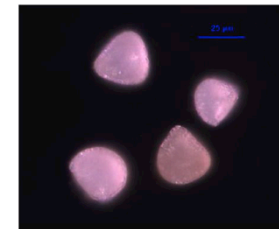
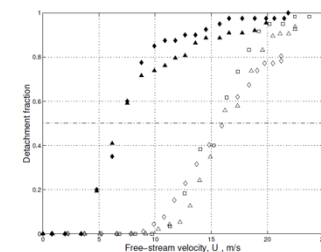
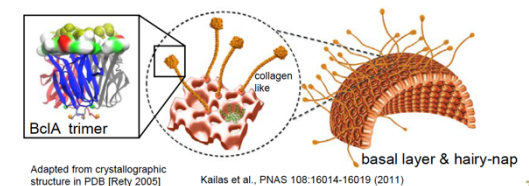


Figure 3.10. A close up of the LY30 microparticles taken with an Olympus optical microscope.



exosporium: forest of hairs



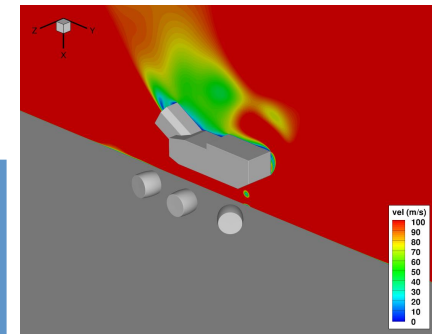
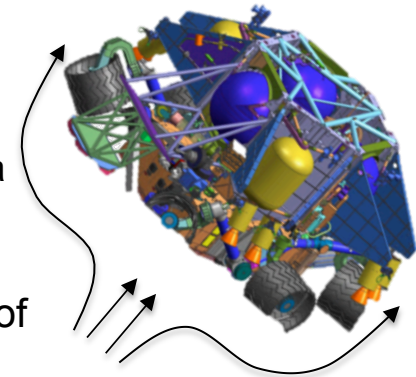
EDL Wind Cleaning (2/2)



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- EDL Wind magnitudes:
 - Bottom: > 140 m/s, greater than 2x any hypothesized surface wind phenomena
 - Sides: > 80 m/s, greater than any hypothesized surface wind phenomena
 - Top: > 50 m/s, greater than all but largest dust devil wind magnitude
- Some fraction of the Rover's surface will experience winds far in excess of those in surface operations
 - Winds will remove some fraction of biological and abiotic particles that would later be released during Mars surface operations



Rover zone (69m ² total)	VOs in zone before wind cleaning	Sheltered Fraction	Unsheltered Fraction	Removal Fraction of biological particles that will later be removable by surface winds in Unsheltered Region	Remaining VOs in Zone after EDL Wind cleaning
Top Deck (35m ²)	$(35/69) \cdot 8(10)^6$ $=4.0(10)^6$	10%	90%	99%	$4.4(10)^5$
Mobility/Sides (25m ²)	$(25/69) \cdot 8(10)^6$ $=2.9(10)^6$	5%	95%	99%	$1.5(10)^5$
Bottom (9 m ²)	$(35/69) \cdot 8(10)^6$ $=1(10)^6$	1%	99%	99.9%	$1(10)^4$

UV Cleaning in First 3 Sols

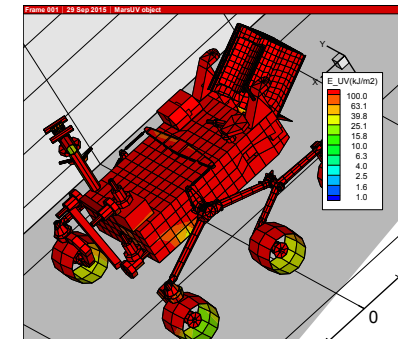


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- Direct and reflected UVC (200-400 nm) illumination modeling
 - Represent Nastran flux analysis for direct and reflected UV
- UV Sol 0-2 Dose and Kill Magnitudes:

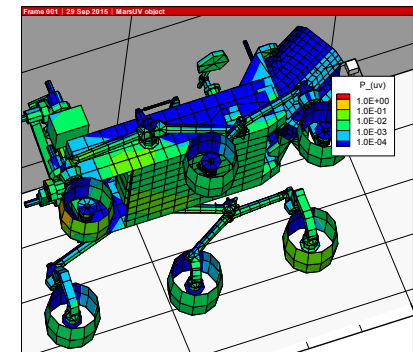
Rover Zone (unsheltered)	UVC Deposition (kJ/m ²)	Literature kill factor (4kJ/m ²)*	8020.12 Appnd D kill factor (180kJ/m ² = 10 ⁻⁴)
Top Deck	300	75x	2x
Mobility/Sides	75 - 300	19x-75x	~10 ⁻² - 2x
Bottom	75	19x	~10 ⁻² (interpolation)



Literature Values: <4kJ/m² for surface sterilization

- Some surfaces will take many more Sols to accumulate kill doses.
 - Will not include those surfaces in calculation

Rover zone (69m ² total)	VOs in zone before UV cleaning	Sheltered Fraction	Unsheltered Fraction	Assumed Kill Fraction Sol (0-2) of biological particles in unsheltered region	Remaining VOs in Zone after UV cleaning
Top Deck (35 m ²)	4.4(10) ⁵	1%	99%	99.99%	4.4(10) ³
Mob/Sides (25m ²)	1.5(10) ⁵	5%	95%	99%	9(10) ³
Bottom (9 m ²)	1(10) ⁴	1%	99%	99%	1(10) ²

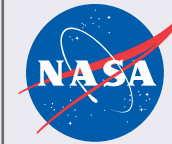


P(uv) using NPR 8020.12D Appendix D (uses 180kJ/m² for 10⁻⁴ reduction)

- What about shading of dust from landing event and Mars wind?
 - See following

*J.N. Benardini conversation 9/25/15

Curiosity Top Deck Dust @ Landing



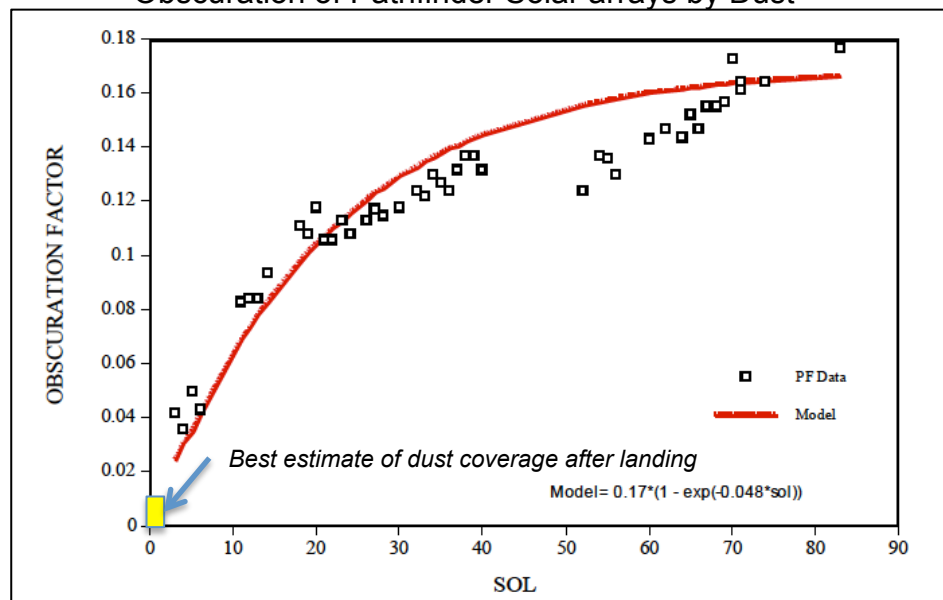
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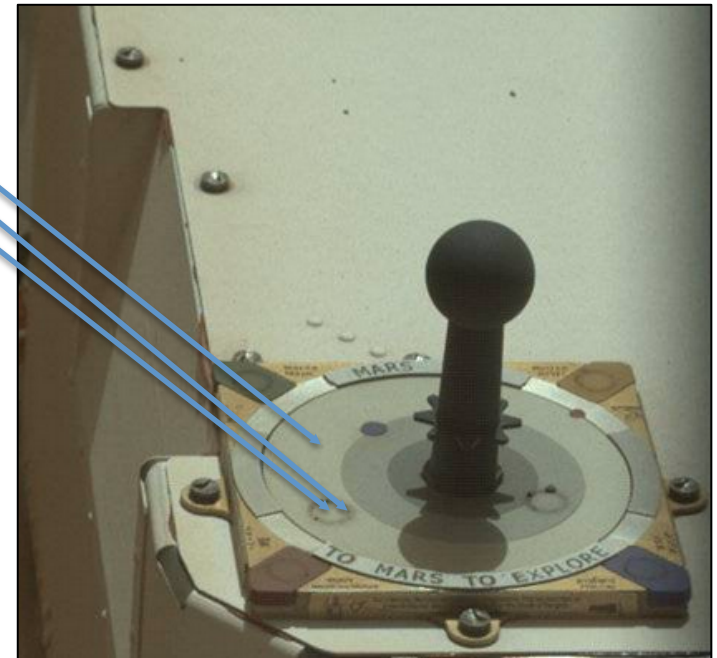
Region	Red DN	Green DN	Blue DN	R/B ratio	Normalized	Note
1	163	171	147	1.11	1.00	non-magnetized
2	135	139	114	1.18	1.07	dust ring (magnet)
3	165	173	149	1.11	1.00	clean surface (sweep magnet)

- Region 1 shows no appreciable increase in red count on non-magnetized surface exposed to dust fallout during landing event
- Region 2 provides “worst-case” magnetized accumulation region
 - 0.07 Obscuration Factor
- Region 3 provides clean dust free surface used as “baseline” R/B ratio

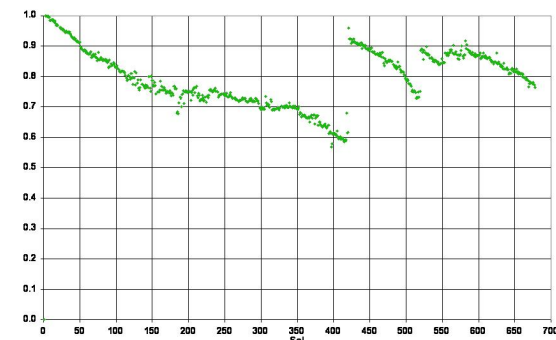
Obscuration of Pathfinder Solar arrays by Dust



(Crisp, D., Pathare, A. and Ewell, R. C., "The Performance of GaAs/Ge Solar Cells at the Martian Surface," submitted to Acta Astronautica, 2001.)



Curiosity Mastcam Cal Target (Sol 2)



Spirit Dust Cleaning Events

What is our gradient at Sol 2?



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	Rover at Large	Turret + Arm	Sample Handling Enclosure
MSL @ Launch	20.5 k Spores ^c		
M2020 Requirement @ Launch	40 k Spores^c	~2000 Spores^c	~600 Spores^c
Launch Terrestrial Viable Organisms	40k*1000 = 40M VO	2M VO	600k VO
Cruise disinfection	0.2X	0.2X	0.2X
@ Entry Organisms	8(10) ⁶ VO	4(10) ⁵ VO	1.2(10) ⁵ VO
EDL Wind Cleaning	6.2(10) ⁵ VO	4(10) ⁴ VO	1.2(10) ⁵ VO (no change)
UV-C Sol 0-3	1.4(10) ⁴ VO	4(10) ³ VO (turret bathing)	2.4(10) ⁴ VO (20% shadowing)
Post Sol 2 VOs	1.4(10)⁴VO	4(10)³ VO (turret bathing)	2.4(10)⁴ VO (20% shadowing)



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Bounding Meta-Analysis

Bernard



Baseline Approach

- In March, we showed our baseline analysis technique
 - Relies on specific information about particle adhesion
 - Results show very large margins

Can we bound these results without reliance on the details of those models?

- High level back-of-the-envelope analysis shown here
 - Limited number of assumptions
 - In many cases the detailed analysis to come is already expected to demonstrate orders of magnitude additional margin
 - See “Notes” column for improvement opportunities
- Detailed network particle transport analysis in development

Major Contributors



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- Definitions:
 - VO: Viable Organisms (Terrestrial)
 - TVO: Total Viable Organisms (Terrestrial)
- Requirement: probability of VO in tube < 0.0001 (1 in 10,000)
- Major Contributors:
 1. VO in Tube, Caging Plug and Sealing Plug prior to sampling
 2. VO on Mars at sampling location
 3. VO transfer from rover during Sampling Operations
 4. VO transfer from Caching Assembly during Caching Operations

Contributor 2: VO on Mars at sampling location



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- Conclusion: about 3 orders of magnitude margin for these assumptions

Case	VO/m ²	Initial Conditions and Assumptions	Note:
VO dislodged during EDL	2x10 ⁻⁶	<ul style="list-style-type: none"> All TVO come off during EDL 80% Cruise die-off Surface Winds average ≥ 1 m/s as particles settle to surface 	<ul style="list-style-type: none"> Accounting for surface UV would drive # lower
VO dislodged due to winds during commissioning	7x10 ⁻⁴	<ul style="list-style-type: none"> All TVO come off during commissioning Frequent, variable Winds > 4.7 m/s (mean) during commissioning 80% Cruise die-off 99.8% removed or killed by EDL cleaning/early UV combination. 	<ul style="list-style-type: none"> Particle removal fraction << 1 for small particles (future analysis)
VO dislodged by increased winds close to the sample location	1x10 ⁻⁴	<ul style="list-style-type: none"> 80% Cruise die-off 99.8% removed or killed by EDL cleaning/early UV combination Winds at collection double the peak winds during commissioning and no more than 1/5 of TVO dislodged by any given octave of wind speeds for speeds < 60 m/s 	<ul style="list-style-type: none"> Particle removal fraction << 1 for small particles (future analysis)
VO released by unmodeled processes close to sample location	7x10 ⁻⁶	<ul style="list-style-type: none"> Mean winds of 4.7 m/s assumed 80% Cruise die-off 99.8% removed or killed by EDL cleaning/early UV combination. No more than 1% of VO come off rover due to unmodeled processes 	<ul style="list-style-type: none"> Not excluding particles removed during commissioning
Requirement	< 0.7		

- Robustness Check – the dust storm VO distribution model shows only about an order of magnitude increase in VO on the surface of Mars at the sampling location due to higher association of VO with large particles in dust storm than in clean room.

Contributor 4: VO transfer from Caching Assembly during Caching Operations



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Case	VO	Initial Conditions and Assumptions	Mitigations not yet taken
VO dislodged due to winds during caching operations	Very low (future analysis)	<ul style="list-style-type: none"> 80% Cruise die-off Short duration operations <ul style="list-style-type: none"> Likelihood of first time high winds during ops very low 	<ul style="list-style-type: none"> VHP Caching Assembly Apply UV prior to ALTO closeout Apply UV at Mars prior to caching operations Seal Caching Assembly during Caching Operations
VO dislodged due to vibration during caching operations	Very low (future analysis)	<ul style="list-style-type: none"> 80% Cruise die-off Short duration operations Follows much higher vibrations during commissioning and coring 	<ul style="list-style-type: none"> VHP Caching Assembly Apply UV prior to ALTO closeout Apply UV at Mars prior to caching operations
VO transferred from volume probe	1E-9	<ul style="list-style-type: none"> Cleaned to < 30 hardy spores/m², then 4 log reduction Protected from recontamination 	
VO dislodged by unmodeled processes during caching operations	1E-5	<ul style="list-style-type: none"> 80% Cruise die-off 10 square meters cleaned to 30 hardy spores/m² >100 sols prior to sampling Random drop off from unmodeled processes Short duration operations (< 1 hour exposed) No more than 1% of VO come off rover due to unmodeled processes Only ¼ of Caching Assembly surfaces are in locations allowing a particle to fall into a tube 80% kill from reflected UV from Mars surface over > 100 sols (assumes not sealed) 	<ul style="list-style-type: none"> VHP Caching Assembly Apply UV prior to ALTO closeout Apply UV at Mars prior to caching operations
Requirement	< 0.0001		

Meta-Analysis Summary



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- Contributor 1: VO in [Tube, Caging Plug and Sealing Plug](#) prior to sampling
 - Controllable by engineering processes
- Contributor 2: VO on Mars at sampling location ([surface of Mars](#))
 - Showed expectation that adhesion-based particle resuspension models will demonstrate excellent margins
 - Further particle transfer test and analysis planned
- Contributor 3: VO transfer from rover during [Sampling Operations](#)
 - Controllable by engineering processes
- Contributor 4: VO transfer from Caching Assembly during [Caching Operations](#)
 - Dominated by assumptions on unmodeled particle “will”
 - If VO release within the caching assembly by unmodeled processes is considered significant, additional mitigations are available to put the issue to bed
 - Further particle transfer test and analysis planned



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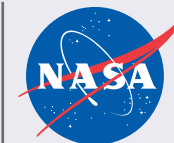
Special Topics and Summary

Bernard



- Special Regions
 - Have proposed an alternate requirement for off-nominal impact into hydrated minerals to replace the wording on the likely over-restrictive one in the partial category letter – while meeting the intent
- Exterior of tubes/definition of “subsystem”
 - The design and architecture is focused on assuring the cleanliness of the returned samples (inside the tubes)
 - The entire tube (inside and out) is cleaned, undergoes bioburden reduction, and is kept clean until used.
 - The tube will be left on the surface of Mars and the exterior of the tube will be less clean than the inside – and that’s ok as long as the sample (inside the tube) remains clean.
 - Related considerations:
 - Witness sample tubes will make the round trip to help characterize contamination
 - Tubes will be cleaned before opening back on Earth to avoid introduction of contaminants from the exterior
- Test Timing
 - Validation approach documented in PP Plan at PDR, refined timetable in PP Implementation Plan and Contamination Control Plan at CDR

IVb Subsystem Definition for M2020



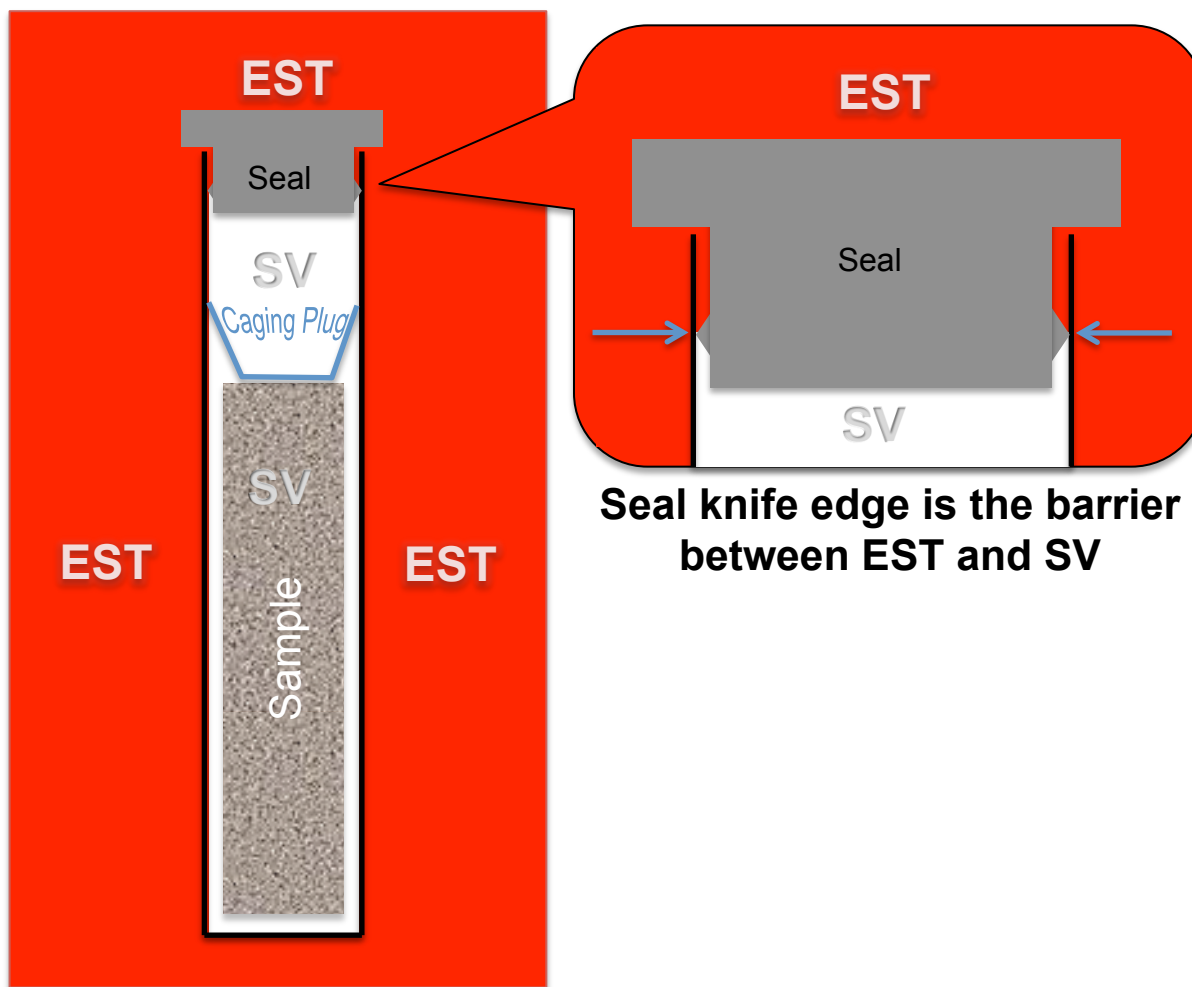
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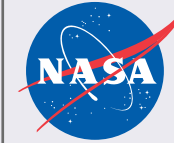
- The IVb subsystem is defined differently pre- and post-sealing.
 - Pre-sealing the IVb subsystem includes **the sample tube, caging plug, and sealing plug.**
 - Post-sealing the IVb subsystem includes **only those parts for the tube, caging plug and sealing plug interior to the effective location of the seal.**

Sealed Volume = **SV**

Exterior of the sealed tube = **EST**



Summary



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- Mars 2020 project has base-lined and architected a mission that can acquire samples and seal them such that they are returnable from a cleanliness perspective
 - Architecture works within heritage H/W constraints and meets the PP/CC requirements
- The approach is based on sealing clean elements of the system until needed during operations on Mars and conducting operational transport analysis to ensure that samples are not contaminated during operations
 - Project believes that this approach is consistent with 8020.12 “subsystem” methods, and standard CC industry practices
- Project believes that this design/approach is implementable and represents acceptable risk
- Continually working with PPO to address potential gaps and concerns